Metropolitan Transportation Commission
Travel Time Data Collection Pilot Project

Final Report

April 1999

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Method	Sufficiency			Coverage			Cost		Local Experience	Observations
	Best Applications	Accuracy	Variability	Geographic	Time of Day/ Market[1]	Modes	Hardware[2]	Maint/Op (per year)		
Immediate Implementation Possible										
Floating Cars • GPS • DMI	• Deficiency ID • Project Program.	Excellent	Limited	Full coverage very costly	Time of day: poor (best for peak)	No Bike	$50,000	$300,000	Excellent	• Cost inefficient but low risk • Too costly to collect data over broad arterial network or in non-peak periods • Feasible but very costly to collect data for transit, freight, and HOV modes
Transit Schedules	• Customer Perception	Fair	None	Full coverage in-expensive	Time of day: all	Transit only	None	Negligible	Excellent	• Not uniformly reliable for individual routes; may supplement with on-time performance statistics • Not reliable for systems that do not routinely monitor on-time performance
Retrospective Survey • Home telephone • Employer • Piggy back on other efforts	• Customer Perception	Limited	Limited	Full coverage possible; costs vary	Markets: primarily commute	No Freight	None	Home: $50,000 per 1000 complete Employer: $5,000 per 1000 complete Piggyback: negligible	Excellent	• Data generally less precise than prospective surveys • Costs decrease as tolerance for bias increases (sampling can be less rigorous, e.g. some employee surveys); makes data less useful for other planning purposes; biases in a web-based survey are most likely unacceptable • Other variations on sampling possible • RIDES effort is most comprehensive existing commuter survey; more complicated to coordinate with many smaller surveys.
Prospective Home Survey (Manual trip diary)	• Customer Perception	Fair to Good	Fair	Full coverage costly	Markets: all	No Freight	None	$150,000 per 1000 complete	None	• Most expensive and most accurate survey method • GPS diaries have excellent accuracy but increase costs and require a long term implementation time frame
Short Term Implementation Possible (1-2 years)										

[1] Time of day refers to peak, off-peak, night, and weekends. Market refers to commute and non-work.

[2] To establish a common basis for comparison, costs were estimated for full MTS coverage unless otherwise specified.

Freight Tracking • Logs • GPS	• Customer Perception	Excellent	Yes, but limited by sample size	Coverage dependent on participants	Time of day: all	Only Freight	$100,000	$100,000	Limited	• Reliance on carriers to provide data likely impractical due to imposition on carrier • Loaner GPS units costly but provide incentive for carrier participation and increase accuracy

Exhibit 2: Evaluation Summary

Method	Sufficiency			Coverage			Cost		Local Experience	Observations
	Best Applications	Accuracy	Variability	Geographic	Time of Day/ Market[3]	Modes	Hardware[4]	Maint/Op (per year)		
Immediate Implementation Possible										
Floating Cars • GPS • DMI	• Deficiency ID • Project Program.	Excellent	Limited	Full coverage very costly	Time of day: poor (best for peak)	No Bike	$50,000	$300,000	Excellent	• Cost inefficient but low risk • Too costly to collect data over broad arterial network or in non-peak periods • Feasible but very costly to collect data for transit, freight, and HOV modes
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Roadside Sensors • Loops/ RTMS (spot speeds)	• Deficiency ID • Project Program. • Real Time Ops./ Traveler Information	Excellent (for spot speeds, assuming adequate maint.)	Excellent	Full coverage costly	Time of day: all	Best for freeways	$4,000,000 to complete existing freeway system	$50,000	Good	• Loops with communications currently operational for 1/6 of fwy system; next 1/6 scheduled to be operational by 2001. • Current loop infrastructure unreliable; fewer than 1/3 of loops actually functioning at any time • Possible to extrapolate travel time from speed data, depending on accuracy need • Vehicle signature matching, under development; may generate travel time data in the long term.
Long Term Implementation Possible (3-5 years)										
ETC Passive Probes	• Deficiency ID • Project Program. • Real Time Ops./ Traveler Information	Excellent	Excellent	Full coverage costly	Time of day: all	All, bike possible	$9,000,000	$300,000	None Yet	• ETC tags cheap, but roadside readers costly; therefore costly to get broad coverage, especially on arterials and therefore on transit • Deployed successfully in other areas • Vehicle type identification non-trivial to implement
Areawide Passive Probes (GPS)	• Customer Perception • Deficiency ID • Project Program. • Real Time Ops./ Traveler Information	Excellent	Good	Full coverage inexpensive	Time of day: all	No bike	$9,000,000	$300,000	None Yet	• GPS units currently expensive and complicated to install (by operators); costs may decrease but this is a risk factor • Collecting data from GPS units is costly, and likely inconvenient • The only non-survey method that can collect door-to-door travel time.
Digital Aerial Photos	• Deficiency ID • Project Program.	Good	Fair	Full coverage costly	Time of day: low light limitation	No Bike	$50,000	$300,000	Limited	• Low light limitation may exclude portions of the peak periods in winter • Photo measurement is labor intensive and no feasible without advances in digital processing
License Plate Matching w/ OCR	• Deficiency ID • Project Program. • Real Time Ops./ Traveler Information	Excellent	Excellent	Full coverage costly	Time of day: all	No bike	$15,000,000 (assuming permanent stations)	$300,000	None	• Manual matching possible in short term but cost prohibitive without (long term) advances in OCR • Video equipment also expensive, especially to cover broad arterial network; therefore limited transit coverage

1. INTRODUCTION AND EXECUTIVE SUMMARY

This project, The Travel Time Data Collection Pilot Project, was conducted to help MTC and the Partnership decide whether and how to pursue system-wide monitoring of travel time and the variability of travel time. Interest in these data evolved from work, conducted for MTC by David Jones in 1995, that identified door-to-door travel time and variability of travel time as key customer-oriented system performance measures. The Travel Time Pilot Project sought to extend Jones' work by identifying, testing, and evaluating promising data collection methods to support a "state of the system report" that would facilitate better understanding of customer experiences and track changes in the performance of the Metropolitan Transportation System over time.

The study suggests a state of the system report could be supported by a combination of surveys and segment monitoring data collection techniques. Survey methods are well-suited to collect data on customer perception and, depending on the sampling rigor and structure, may provide more general planning data. The evaluation identifies a number of segment monitoring methods suitable for collecting data for a state of the system report but recommends deferring a final decision until the completion of the TravInfo™ data coverage plan. The most promising methods also have potential for real-time data applications, which could be used to justify the substantial infrastructure investments required.

1.1 Project Context

1.1.1 The Metropolitan Transportation System

The Metropolitan Transportation System (MTS) is the subset of the region's multi-modal network that is of regional significance. The MTS was defined to allow the region to focus system management efforts and is an appropriate focus for regional monitoring efforts.

The MTS road system consists of a defined set of streets and roads and represents about 15% of the total road miles in the Bay Area. (See Exhibit 1.) There is no similarly defined subset of transit routes or transfer points. The complete regional transit system includes over two dozen transit operators in the Bay Area providing 7,000 route-miles of service using about 4,000 buses, rail cars, and ferry boats.

Exhibit 1. 1998 Bay Area and MTS Road System Miles

	MTS				Non-MTS	TOTAL
	State Highways		Other	Subtotal		
County	Freeway	Other	Local	MTS		
Total	607.3	818.3	1604.8	3030.4	17758.0	20788.4
% of Total	3%	4%	8%	15%	85%	100%

Source: www.mtc.dst.ca.us/facts_and_figures/misc/cardmile.htm;
www.mtc.dst.ca.us/projects/mts/mts.htm

1.1.2 Customer Oriented Measures and the State of the System Report

In his report, "Intermodal Performance Measures for the Bay Area Transportation System" (June 1995) David Jones makes the case that it is appropriate to measure performance from the customer's perspective which is modally neutral and encompasses the entire system.

Jones' work examines four case studies to develop mobility objectives and potential performance measures for a number of travel markets. The first illustrates that aggregate measures of freeway congestion do not accurately represent the average commuter's experience, commuting convenience or access to jobs, because most commuters live relatively close to work and therefore have limited exposure to congestion. The second illustrates that the most important performance attribute for efficient goods movement is the reliability of travel times. The third and fourth examine transit's contributions to the transportation system in providing access to job centers in the urban core and providing access to those who do not own autos.

Of a number of mobility objectives and performance measures suggested by Jones in this work, MTC has chosen to focus on implementing two as a way to begin work on the potentially vast world of customer oriented measurement: 1) a convenient commute as measured by door to door travel time; and 2) system reliability as measured by variability of day to day travel times for selected links of the Metropolitan Transportation System (MTS). MTC envisions these measures could be used to better understand customers' experiences, track system performance over time, and identify potential deficiencies that may require further investigation. In addition to sharing data with Partner agencies, MTC proposes publishing the data in a periodic state of the system report available to the press and the public.

1.1.3 Other Possible Applications for Travel Time Data

With the pilot project, MTC wished to identify and evaluate techniques for collecting travel time and related data to support a state of the system report. The evaluation framework initially was developed to assess the ability of data collection techniques to gather door-to-door travel time by mode and market at reasonable cost. The need to clarify and distinguish several applications for travel time and related data, such as speed and delay, became increasingly apparent as the Pilot Project progressed. Each potential application has specific data requirements.

The two applications most directly related to the state of the system report described above carried the most weight in this study's evaluation of data collection methods:

1. <u>Public Information on Customer Perception (or Customer Satisfaction)</u> – David Jones' vision for using door to door travel time as a customer oriented measure extrapolates most readily to this application.

2. <u>Deficiency Identification</u> – Data would be used to track changes in performance over time, flag potential problem areas, and prioritize planning efforts.

Three other applications for travel time data become relevant because economies of scope are achieved when data collected for one purpose may be used for others. Though this study does not attempt to define data needs for other applications, it offers a preliminary evaluation of the ability of various data collection techniques to address the following:

3. Guiding Investment Decisions – Data could be used to help prioritize projects for funding.
4. Real-time System Operations – Data would be used to identify and respond to incidents and congestion in real-time.
5. Real-time Traveler Information – Data would be disseminated to the traveling public to inform decisions on mode and route choice and departure time.

This study does not focus on these applications as MTC has no commitment at this time to use travel time data to guide investment decisions and MTC's TravInfo™ group is conducting separate study to explore data needs for real-time traveler information and system operations. MTC expects to complete the TravInfo™ study in Summer 1999.

1.2 Project Approach

The Pilot Project began with a preliminary evaluation of all available techniques for measuring travel time. The purpose of the preliminary evaluation was to identify potential methods for collecting travel time data, narrow the list of potential methods, and identify candidate methods for field testing. The evaluation criteria were developed early in the course of the project and focus on the suitability of methods to collect data for the state of the system report envisioned by MTC. Criteria applied in the evaluation include:

- Coverage (modal, temporal/market, and geographic),
- Cost (capital and maintenance),
- Local experience and potential to coordinate with local agency efforts,
- Length of time necessary to implement,
- Sufficiency of data for customer perception and deficiency monitoring in support of a state of the system report; sufficiency considers data accuracy and the ability to collect door-to-door travel time and variability data. The sufficiency criterion also addresses these factors with respect to the other three applications for travel time and related data.

Field testing was performed in August and September 1998 to explore techniques for which inadequate data was available in the published literature. Tests included low cost techniques for distributing and collecting employer/employee surveys using public agency staff and employer trip reduction coordinator volunteers. A web-based survey instrument with e-mail notification was tested along with a simple paper survey instrument. Transit agencies and private freight carriers were also contacted and interviewed to determine the methods they currently employ to monitor their system performance and the potential for sharing this information (or participating in a special data collection effort to obtain travel time performance data) with MTC.

A telephone survey instrument was developed in parallel with the field tests. The survey instrument is designed to solicit travel time data and information on traveler perceptions.

The last task in this project was to evaluate the results of the previous tasks and develop some technical options for MTC to pursue in developing a data collection program for its state of the system reports. The final evaluation and recommendations, contained in this report, reflect the combined results of the preliminary evaluation and the field tests.

1.3 Summary of Data Collection Techniques

People's travel time exists in three dimensions: time, space, and the trip makers themselves (see Exhibit 2, note that the diagonal lines represent vehicle trajectories). Travel time data collection techniques take samples from one dimension, and measure travel times across the other two dimensions. For example, loop detectors measure the speeds of all vehicles passing by, all day, (2 dimensions) but they only provide this information for a small sample of all the geographic locations in the region (the third dimension). By understanding how each technique samples the universe we can understand their basic strengths and weaknesses. Detailed descriptions of each technique can be found in Chapters 2, 3, and 4.

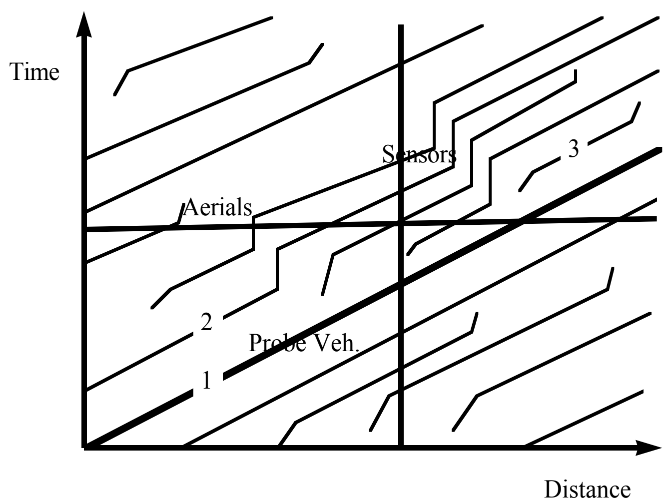

Exhibit 2. The Travel Time Measurement Universe

There are numerous speed and travel time measuring techniques, but they can all be grouped into three large categories according to their method of sampling the travel time universe.

1. Spot speed measurement techniques measure vehicle speeds only for a given point of geography or a given point of time. They sample either the horizontal or the vertical axis in Exhibit 2.
2. Vehicle tracing techniques measure vehicle travel times only for a select portion of all trips[1]. These techniques sample the diagonals in Exhibit 2.

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[1] For example, the probe vehicle (trajectory #1) measures a mean travel time representative of only vehicles that are able to traverse the length of the corridor without hitting a red light. The travel times of slower (trajectory number 2) or faster vehicles in the corridor is not measured, so the variance between trips is unknown. And some short trips that use only a portion of the arterial (trajectory number 3) are not measured at all.

3. Trip maker tracking techniques are similar to vehicle tracing techniques but measure traveler trip times rather than vehicle trip times. These techniques also sample the diagonals in Exhibit 2.

1.3.1 Spot Speed Measurement Techniques

Spot speed measurement techniques measure the instantaneous speeds of vehicles either at specific spots of the roadway or at specific times of the day. These techniques are very cost effective at gathering large amounts of speed data for specific segments of the transportation system but cannot provide door to door travel times. Roadside sensors and aerial photography are the two main spot speed measurement techniques:

- **Roadside Sensors:** Roadside sensors include in-the-road loop detectors, roadside radar, microwave sensors, video sensors, and infrared sensors. They are "location based sampling" methods which suffer from the biases inherent in measuring speeds at a point and assuming the speed is applicable to other points on the roadway. Technological variations include: single loop detectors, double loop detectors, portable machine double hose counters, radar, microwave, and infrared sensors, and video camera sensors. Recent technological advances, such as vehicle signature and platoon signature matching may allow measurements of elapsed time between loop detector stations, thus eliminating the bias of spot speed measurements.

- **Aerial Observation/Photography:** Aerial observation involves recognizing congestion spots on the highways from the air. Aerial photography measures the speeds of vehicles at one point in time over the geographic area covered by the photos. Tests of aerial photography against floating cars have found speeds measured from photos can be reliably extrapolated to obtain point to point travel times. The costs of data reduction from the photos is the single greatest drawback to the use of aerial photography. Technological variations include: simple manual observation, time lapse photography, density photography, digital camera photography, digital scanning of film, and satellite imagery.

1.3.2 Vehicle Tracing Techniques

Vehicle tracing techniques involve tracking either test vehicles or randomly selected vehicles through to determine the travel times between pre-selected check points. Vehicle tracing techniques are an example of "trip-based" method of sampling travel times. They are good techniques for measuring trip segment travel times (a geographic portion of the traveler's total trip). However, they generally are not easily adaptable to measurement of door to door travel times, because of the expense and difficulty of obtaining a reasonable sample of door to door locations.

Vehicle tracing techniques consist of: Test Vehicle, Non-Instrumented Vehicle Tracking, and Passive Probes.

- **Test Vehicle (Floating Car) Technique:** The test vehicle technique is the most common travel time collection technique employed to date. This technique consists of hiring a driver and vehicle to drive a vehicle along a pre-selected route and measuring the elapsed time and distance traversed. Labor saving variations equip the test vehicles with distance measuring instrument (DMI) or global positioning satellite (GPS) to automate measurement and recording and to eliminate the need for a second person in the vehicle.

- **Non-Instrumented Vehicle Tracking Technique:** This technique uses any one of several technologies for identifying randomly selected vehicles at various checkpoints within the study area and measuring the time between appearances at each checkpoint. Vehicle tracking is different than using test vehicles, because the drivers have not been hired to do the study. Technological variations include: License Plate matching, License Plate matching with matching software, and Loop detectors with vehicle signature matching.
- **Passive Probe Technique:** This technique require some sort of special tracking instrumentation on the vehicles as well as the roadside. The vehicle driver is not hired to drive a particular route and goes about his or her normal business. Either readers are mounted on the road to record the time and identity of all transponder equipped vehicles passing by, or readers are mounted in the vehicle to record the times and movements of the vehicle past each transponder location. Technological variations include: Automatic vehicle location (AVL), Automatic vehicle identification (AVI), Emergency vehicle tracking, Cellular phone geolocation, and Global positioning satellite (GPS).
- **Transit Vehicle Tracking Techniques:** The previous vehicle tracing techniques are applicable to all vehicles, including transit vehicles. The discussion under this category focuses on the special issues involved in working with public transit agencies to monitor public transit vehicles. Most public transit operators already publish route schedules and monitor on-time performance. A few operators are able to use automated techniques for tracking vehicle movements, but most currently rely upon manual checkpoint and ride check techniques. The data is stored in varying formats in varying software formats, making electronic transmittal of data difficult.
- **Truck Tracking Techniques:** Trucks can also be tracked using all of the previously described vehicle tracking techniques. Tracking trucks though requires the active cooperation of the vehicle fleet owner who must consent to the placement of any special devices in the vehicle, or must transcribe manual logs and share the information with interested public agencies. Public agencies wishing to track commercial vehicles must demonstrate to the vehicle fleet owner that the owner will receive some direct benefit in return for the expense of transcribing and sharing the vehicle tracking information. In most cases, travel time information is mixed in with sensitive proprietary information on customers, and must be manually sorted out by the operator before it can be transmitted to a public agency.

1.3.3 Tripmaker Tracing Techniques

Trip maker tracing techniques survey travelers either after they have completed their trip or recruit volunteers in advance to record and report their travel times as part of their daily activities.

- **Retrospective Surveys:** Retrospective surveys quiz the traveler about their trip travel times and experiences after the fact. The traveler is not prepped in advance, so questions must be limited to what can be reasonably remembered from the previous day's or that morning's commute. Variations explored here include: household telephone surveys, surveys of employees at their work sites, and website/e-mail surveys
- **Prospective Surveys:** Prospective surveys involve at least two contacts with each individual: one contact to recruit the individual, and a second to collect the information. A third contact may be required to deliver a trip diary form or a GPS unit to the individual to aid in recording information. Travelers can be asked in advance to note a great deal of detail about their trips, including travel times for specific segments of the trip. Technological variations include: global positioning satellite receivers/ recorders, e-mail reporting, and cell phone call-in.
- **Utilizing (Piggybacking) Other Surveys:** Public agencies currently survey at least 22,000 commuters in the Bay Area every couple of years. Two agencies, VTA and Rides, survey about 2,600 households in the Bay Area every two years. Only the Rides survey currently asks travel time information but the others could be easily modified to include a couple of questions on travel time. Adding more than just a few questions, however, could significantly impact survey processing costs. MTC also conducts its own prospective survey of 10,000 households every 10 years to collect extensive data on travel habits and trips times. Any of these surveys are resources that could be used to monitor door to door travel times in the Bay Area.

1.4 Summary of Findings

After investigating a large number of data collection techniques, this study confirmed suspicions that there is no simple, inexpensive solution for collecting travel time data. Nonetheless, several conclusions can be drawn.

Results from the evaluation are summarized in Exhibit 3 and lead to the following findings:

- Survey methods are best suited to collect data on customer perception and can be implemented immediately. MTC currently conducts comprehensive prospective household travel surveys approximately every 5 years. While it would be prohibitively expensive to increase the frequency of these efforts, these efforts can serve as anchors or calibration points for less comprehensive surveys conducted more frequently. Surveys will also provide an opportunity to ask a range questions related to customer satisfaction with the transportation system. The biggest question, to be answered through discussions with MTC's partner agencies, is the appropriate level of sampling rigor, which will affect data quality and the ability to use the data for a variety of planning purposes. Options range from piggy-backing on the annual RIDES commute survey, which offers statistically significant data by county of residence, to surveying employees through their employers, which offers geographically targeted data with a potentially larger sample bias.
- Segment performance data collected for deficiency monitoring could compliment the survey data by focusing on specific facilities and corridors, which is costly to do with surveys. In addition, segment data can provide a reality check for perception data collected through survey efforts.

  The Pilot Project identifies five methods well-suited for segment monitoring on roadway facilities: floating cars, roadside sensors (spot speeds or extrapolation), passive probes (ETC or areawide), digital aerial photography, and license plate matching with OCR. Except for floating cars and aerial photography, these methods require significant investment in data collection infrastructure and are potentially good for real-time data for operations and traveler information in addition to deficiency monitoring.

  While it would be difficult to justify a major investment in data collection infrastructure solely for the purpose of the state of the system report, it could be justified for real time information. We recommend, therefore, that MTC wait for the outcome of the recently initiated project to develop data coverage plan for TravInfo™, the region's real-time traveler information system, before settling on a data collection method for this element of the state of the system report. The TravInfo™ study, to be completed in summer 1999, will research the types of real-time information travelers seek and analyze existing and potential data sources.
- Both the surveys and the roadway segment monitoring methods can provide data on variability. For the time being, transit on-time performance data, variable among operators, is the best source of data on travel time variability for transit.

Additional conclusions relate to data collection for specific modes:

- Though the use of travel time data estimated from transit schedules is not a good method for deficiency identification, it would compliment data collected through survey efforts. As AVL systems come on line in the next 3-5 years, they may provide better segment travel time and variability data for transit; however, integrating data from a number of sources and in a number of formats could still be complicated.
- The best means to collect data applicable to the freight market is to ensure general data collection efforts on freeways and arterials cover heavy freight facilities during periods of peak freight movement. Despite a high level of willingness to cooperate among members of MTC's freight advisory council, it is prohibitively complicated and costly to survey the freight market for a regional state of the system report at this time.
- It is reasonable to rely on survey methods to provide data on bicycle travel.

Exhibit 3: Evaluation Summary

Method	Sufficiency			Coverage			Cost		Local Experience	Observations
	Best Applications	Accuracy	Variability	Geographic	Time of Day/ Market[2]	Modes	Hardware[3]	Maint/Op (per year)		
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1.5 Report Organization

This chapter has provided an overview and summary of the Travel Time Pilot Project and the findings presented in this report. The remainder of the report is organized as follows:

Chapters 2, 3, and 4 describe the various existing, emerging, and innovative techniques available for measuring travel time. Chapter 2 focuses on spot speed measurement techniques including roadside sensors and aerial photography techniques. Chapter 3 focuses on vehicle tracing techniques which include test vehicle (floating car) and license plate matching methods of travel time measurement. These methods track vehicle movement rather than travelers. Chapter 4 focuses on trip maker tracing techniques which includes all manner of surveys that are focused on the traveler rather than the vehicle used.

Chapter 5 evaluates the strengths and weaknesses and the relative suitability of the various techniques for the various possible system monitoring uses to which they might be applied.

Chapter 6 summarizes the conclusions of the study.

2. SPOT SPEED MEASUREMENT TECHNIQUES

Spot speed measurement techniques measure the instantaneous speeds of vehicles either at specific spots of the roadway or at specific times of the day. Roadside sensors (such as loop detectors) measure vehicle speeds at specific spots in the roadway for 24 hours a day. Aerial photography measures vehicle speeds over large geographic areas but only for a short moment in time.

2. SPOT SPEED MEASUREMENT TECHNIQUES

Spot speed measurement techniques measure the instantaneous speeds of vehicles either at specific spots of the roadway or at specific times of the day. Roadside sensors (such as loop detectors) measure vehicle speeds at specific spots in the roadway for 24 hours a day. Aerial photography measures vehicle speeds over large geographic areas but only for a short moment in time.

2.1 Loop Detectors and Other Roadside Detectors

Roadside detectors are permanent or portable instruments located within or alongside the roadway for measuring the spot speeds of vehicles passing selected points of the roadway. Speed information can be retrieved every half minute which causes data storage to be such a problem that traffic monitoring centers typically keep data for less than 24 hours. Loops and roadside detectors are used in several regions to provide real-time travel information on speed. (See h**ttp://www.maxwell.com/caltrans/la/la_big_map.shtml** for spot speeds on the Los Angeles freeway system; **http://www.wsdot.gov/regions/northwest/NWFLOW** for real time freeway operating conditions on freeway in the Puget Sound (Seattle) Region.

Technology variations of this technique include: single loop detection, double loop detection, portable tubes, radar/microwave/infrared, video, and loop detectors with vehicle signature matching.

2.1.1 Single Loop Detection

Single loops in the roadway are designed primarily to count vehicles or to measure occupancy (the amount of time a vehicle spends on the loop). A typical single loop is 6 feet wide and 6 feet long, with one loop located in each travel lane. The amount of time that a vehicle spends on the loop can be used to obtain a rough estimate of the vehicle speed by dividing the assumed length of the vehicle by the passage time (see Exhibit 4). Trial and error may be used to determine the average vehicle length that gives the most reasonable estimates of speeds (calibration of the loop), but this average vehicle length can vary quite a bit depending on the percentage of long trucks crossing the loop. The percentage of long trucks can vary significantly by time of day, throwing off the calibrated average vehicle length for the loop. Single loop detectors will show an apparent drop of 10 mph in vehicle speeds during the early morning hours due the higher proportion of large trucks present in the vehicles streams during those hours.

Speed = Vehicle Length / Occupancy Time

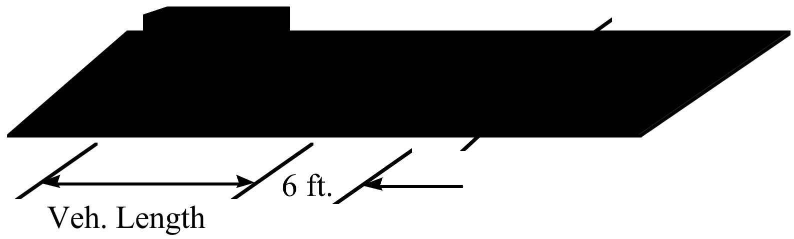

Exhibit 4. Single Loop Speed Measurement

2.1.2 Double Loop Detectors

Double loop detectors provide much more precise measurements of vehicle speeds than single loop detectors. Double loops consist of two 6 foot wide loops located 14 feet apart, one pair of loops in each travel lane[4]. With a double loop, the vehicle speeds are computed by dividing the distance between each loop in the pair by the time it takes the front edge of a vehicle to travel between each loop in the pair by (see Exhibit 5).

Speed = 20 feet / Time

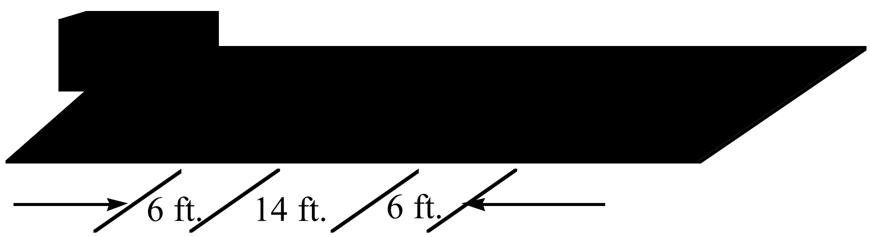

Exhibit 5. Double Loop Speed Measurement

2.1.3 Portable Tube/Loop Detectors

Portable traffic count machines consisting of a counting machine and either rubber tubes or wire loops can be used to temporarily measure vehicle speeds. The count machine is chained to some immovable object (such as a tree) to reduce theft. A pair of tubes or a single loop of wire are connected to the machine and taped or nailed to the road pavement. This operation requires the roadway to be closed (or free of vehicles) for the few minutes required for the technician to install the tubes. For this reason, portable detectors are not feasible for freeways where vehicles are almost always present.

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[4] Source: Caltrans Ramp Meter Design Guidelines, Figure 11, 1993.

2.1.4 Radar/Microwave/Infrared Detectors

Radar, microwave, and infrared detectors are mounted along the side of the road or overhead. An approaching vehicle is irradiated with radar, microwaves, or an infrared beam. The Doppler shift in the frequency of the reflected beam is used to estimate the vehicle speed. Radar, especially hand held devices, requires calibration. Another problem is that radar detectors can only measure the speed of the fastest vehicle in a platoon of vehicles.

2.1.5 Video Detectors

Video cameras have been used to observe congestion or to count cars. Autoscope is an automated video vehicle counting system developed by Econolite. However, there is relatively little experience using video cameras to measure vehicle speeds. A key consideration in the proper operation of video detection is the proper location of cameras (height and angle) to avoid traffic in one lane from blocking the visibility of other lanes, and to avoid the problems of reflected and direct sunlight.

2.1.6 Vehicle and Platoon Signature Matching

Several researchers are studying the use of vehicle signature matching and platoon matching to obtain travel times over lengths of freeway. Vehicle signature matching calculates travel time by matching or correlating unique vehicle signatures between sequential observation points. Vehicles with unique signatures among passenger vehicles include large trucks, buses, and various truck/trailer combinations. Some researchers see vehicle signature and platoon matching as implementable in the near term with existing traffic surveillance infrastructure.

Platoon matching uses similar concepts, except that this method correlates the number of large vehicles within a vehicle platoon between two consecutive locations.

This capability would make loop detectors into vehicle tracking devices, which would give them similar strengths and weaknesses as other vehicle tracking techniques (see the chapter on vehicle tracking techniques for more information on these strengths and weaknesses).

Vehicle signature and platoon matching avoid the "invasion of privacy" issues that might potentially arise with probe vehicle systems that might be misused to provide information on the owners of individual vehicles.

2.1.7 Accuracy

Roadside sensors are limited to the specific points where they are located. Large samples of data are easily gathered, but they are not necessarily representative of the mean travel speed over the length of a facility. Double loop detectors, radar, and video detectors all can measure speeds to the tenth of a mile per hour, but they cannot measure the speed of traffic for more than a few feet of a facility at each point they are located. An exceedingly dense network of roadside detectors would be required to accurately detect the point where traffic congestion begins and ends. Detectors located every one-third of a mile would only be able to predict the beginning or ending point of a queue to the nearest third of a mile. This means that the detector predicted mean speed to traverse a two mile long section of freeway could be as much as 8 mph off from the true mean speed, a 20% to 30% error, depending upon whether the queue starts right on a detector or one-third of a mile away.

Nonetheless, some regions are using travel time data extrapolated from loop data for real-time traveler information. (The website **http://www.trafficassist.com** illustrates how travelers can use loop detector data, after it has been processed by a commercial firm (Traffic Assist), to find their real-time fastest route in Los Angeles.) This suggests the extrapolated travel time data may be accurate enough for some purposes.

The analyst should be sure that the reported mean speed is the "harmonic" mean and not the "arithmetic" mean speed. Since speed is a "rate" (distance divided by time), a simple average of the speeds of vehicles (called the "arithmetic" average) doesn't give the true mean speed of all vehicles. The "harmonic" mean (known also as "space mean speed" in traffic engineering texts) gives the true, unbiased estimate of the mean speed of traffic. The use of the arithmetic mean rather than the harmonic mean can introduce another 1% to 10% error in the estimate of the mean speed.

One must also be careful of potential geographic bias that might occur when trying to use roadside sensors that were originally designed for traffic signal or ramp metering control. A study by Dowling for Caltrans found that traffic signal loop sensors are not suitably located and designed to produce reliable estimates of mean trip speeds for arterials (see Exhibit 6). There was a significant bias in the loop detector mean speed (the difference in mean speeds was over 5 mph when compared to floating car runs). The aerial photo mean speed had a much less strong bias.

Exhibit 6. Accuracy of Arterial Speed Measurement Methods

Method	Mean Speed	Difference	Sample Size	Standard Deviation[5]
Floating Car	25.0 mph	-	24	2.0 mph
Aerial Photos	23.6 mph	-1.4 mph	1,815	15.1 mph
Loop Detectors	30.5 mph	+5.5 mph	186,000	11.3 mph

Data for four hours on 10 mile section of Ventura Boulevard, Los Angeles. Single loop and time lapse aerial photo techniques compared to floating car. Source: R.G. Dowling & W.W.K. Cheng, "Evaluation of Speed Measurement and Prediction Techniques for Signalized Arterials", Transportation Research Record 1564.

Vehicle signature matching can over come the geographic limitation and bias of loop detector measurements.

2.1.8 Cost Information

Caltrans has loop sensors in place on approximately 110 of the 600 centerline miles of freeway in the Bay Area. Loop detectors are located on the average of one set every third mile (6 sets for every centerline mile). Thus there are a total of approximately 660 loop sensors in place now on the region's freeways. Approximately 300 of these are hooked up to communications systems to

[5] The standard deviations are much higher for aerial photos and loop detectors because they include a much broader sample of vehicle routes than the floating cars.

provide information to TravInfo™ and the Caltrans Transportation Management Center (TMC). Of these, about 30% (about 100 sensors) are operational at any one time (source: Michael Berman, MTC, 510-464-7717).

Caltrans plans are to install wireless modems to communicate with 300 additional loop sensor stations by the end of 1999. This would provide communications for an additional 50 centerline miles. A further 300 loop sensors with modems would be installed by the end of the year 2000 (another 50 miles). This would result in coverage for about one-third of the entire freeway system by the end of the year 2000.

Caltrans staff have indicated that their ultimate, long term goal is to instrument about 500 of the 600 miles of freeway in the Bay Area, but there are no definite written plans stating this goal (source: Albert Yee, Caltrans, 510-286-4542).

Caltrans also has plans to install 520 closed circuit television cameras (CCTV's) to supplement its loop detector incident detection system (source: Cyrus Mashoodi, Caltrans, 510-286-6911).

MTC is installing about 22 micro-wave RTMS radar detectors (should be operational February 1999). These detectors are being installed with the intention that sensors not located in the pavement would not be as subject to failure as loop detectors.

It costs about $12,000 to install a set of freeway loop detectors for four lanes with a cabinet and a computer to store the volumes of information produced by loop detectors. Another $2,000 to $8,000 per cabinet is required for wireless communications with the central traffic management center.

Maintenance is another significant cost item. However, information on loop maintenance costs, separate from regular highway maintenance, is not available. Loop detectors require a significant amount of monitoring and repair to ensure their nearly continuous operation. Loop detector reliability is a significant problem for most traffic monitoring systems. Poor pavement conditions and road construction/maintenance projects are frequent problems for maintaining loop operations.

Alternative roadside sensor systems, such as overhead video cameras, can avoid many of the pavement maintenance problems of loop detectors.

2.1.9 Local and National Experience

Loop detectors are a well established technology for gathering speed data.

Two salient examples of the use of loop detectors and other roadside detectors for obtaining spot speed data are:

- PATH and Caltrans - There is currently a project underway in Orange County, California to test the use of loop detectors to collect the *variability* of travel time data. Data collection was scheduled for the summer of 1998.
- MTC Freeway Service Patrol Feasibility Study - PATH (a branch of the University of California, Berkeley, Institute of Transportation Studies) used floating cars and loop detectors to measure the impact of the freeway service patrol (FSP) on travel times

and speeds on the I-880 Freeway in Hayward (contact: Dr. Alex Skabardonis 510-642-9166).

The University of California PATH project is currently developing and testing video detection equipment and software mounted on top of an office building near the I-80 and Powell Street interchange (contact: Dr. Alex Skabardonis 510-642-9166).

Information on recent vehicle signature tracking research can be obtained from Mr. Benjamin Coifman, Ph.D. candidate at the University of California, Berkeley, (510-642-3585, direct line 642-9907). He is currently completing his dissertation on “Vehicle Re-identification and Travel Time Measurement on Freeways Using Simple Vehicle Signatures”.

2.2 Aerial Photography

Aerial photography has been used for several years to measure congestion, but is a relatively recent innovation for measuring vehicle speeds over large areas. Large amounts of data over large geographic areas can be gathered very quickly. The prime disadvantage is the labor involved in identifying and counting the vehicles in the photos. Another disadvantage is that aerial photography is feasible only when minimum requirements for lighting and visibility are met.

Several problems can occur with aerial photography that do not normally occur with land based measuring methods.

- *Weather:*
  Low level fog or clouds (below 9,000 feet), and high winds can prevent the aircraft from either being able to get a good image of the ground or to stay on the desired course.
- *Finding Adequate Sunlight*
  Aerial photography requires sunlight. Long shadows also interfere with vehicle detection in the photos. There is adequate light if the flights are flown 1/2 hour after sunrise to 1/2 hour before sunset.
- *Air Traffic Control*
  If the desired flight path for photography falls in the approach to a major airport, certain photography flights may be canceled at the discretion of the airport approach control.

Technology variations of aerial photography include: time lapse photography, vehicle density photography, digital cameras, digital scanning, and satellites.

2.2.1 Time Lapse Photography

Time lapse photography involves taking two or three photographs a few seconds apart (see Exhibit 7). With knowledge of spatial scales and of the exact time between photographs, the change in position of a vehicle in two photographs gives its speed. The change in speeds between the first and second, and second and third photographs gives its acceleration. In all of these cases, vehicle type and lane can be identified. Photos are typically shot at about 12000 to 1 scale (one inch equals one thousand feet).

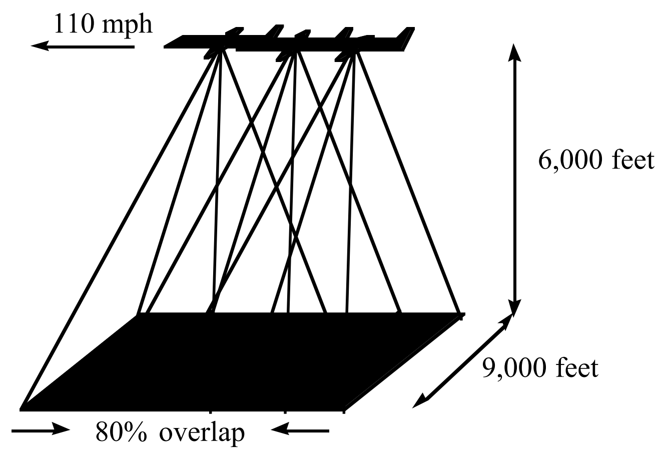

Exhibit 7. Time Lapse Aerial Photography

2.2.2 Vehicle Density Photography

Vehicle density photography requires many fewer photos than time lapse photography, and it is not so critical to be able to reliably scale ground distances in the photos. Photos can be shot at 18000 scale, which is just about the limit of the ability to detect individual vehicles with the naked eye on 9 inch by 9 inch negatives.

The density of vehicles is determined simply by counting the number of vehicles present on a section of the freeway and dividing by the number of lanes and the length of the section.

The density is then converted to speed using a speed-density equation specifically calibrated for the area and facility type. The calibration is based upon floating car runs made on a small portion of the freeway system performed at the same time as the aerial photos were shot. Actual vehicle speeds however can vary by 10 mph or more for a given density, thus even with calibration, this method is still primarily useful for determining freeway level of service (which is based directly on density) and less useful for determining speeds.

2.2.3 Digital Cameras

The manual identification of vehicles in each photo is quite labor intensive Digital cameras offer the opportunity to generate computer readable images directly that might be processed with image processing software. Images are captured and stored as computer-readable files. Digital cameras, however, cannot yet achieve the same resolution and range of light sensitivity as film.

A low cost digital camera, the Kodak DC50 zoom ($800 purchase price), was tested as part of this project. It is a CCD still frame camera with zoom lens (7 to 21 mm). The camera is capable of saving pictures in low, medium, or high resolution. The high resolution setting takes a 756 x 504 pixel image with 24 bit color.

The storage capacity (in terms of number of pictures) is affected by the resolution. At low resolution, it can store 22 pictures. At medium resolution it can store 11 pictures. At high resolution, it can store 7 pictures. The storage capacity can be increased to 720 low resolution pictures or 280 high resolution pictures by adding a 40 MB memory card that costs a few hundred dollars.

The camera was taken up for two test flights. Pictures shot at the highest camera resolution at an altitude of below 2000 feet showed each vehicle composed of several pixels, making it easy to distinguish vehicles. The geographic coverage of each picture at this altitude though is quite small. Pictures taken at 5,000 feet altitude provided the desired geographic coverage within each picture frame, but the vehicles were too small to resolve well. It was consequently concluded that a standard resolution camera would not be satisfactory. Satisfactory resolutions of the vehicles could only be obtained at low altitudes, where the field of view was just too small.

Professional quality “super-high resolution” digital cameras have a 1500 x 1000 pixel array, which allows, for example, an area of 2,400 feet by 1,600 feet to be captured with a resolution of 2 feet. This resolution is adequate to identify vehicles by type, with the exception that motorcycles may not be reliably detected. At this resolution, a pair of photos shot 4 seconds apart would be able to identify vehicle speeds to the nearest half a foot per second, or about a third of a mile per hour.

Two difficulties were encountered in trying to test a super-high resolution digital camera. First, the regular aerial photo firm would not agree to try it. Second, the lone company willing to rent out the camera was unwilling to let the camera go up in a plane without a large insurance policy.

The technology of direct digital photography may have great promise, but it does not appear to be mature enough yet for use in aerial photography.

2.2.4 Digital Scanning of Photos

As an alternative to the use of direct digital photography, digital scanning of photos was tested in this project to determine the feasibility of reducing the labor costs involved in processing time lapse photos.

Selection of film and camera combinations was based on consideration of film speed, film sharpness, and image size. The combination selected was the use of Kodak Pro 1000 film in a medium format (120 or 220 film size) camera. The 1000 ISO speed of the film, combined with the larger image size (6 or 7 cm), was expected to provide good light sensitivity and reasonable spatial coverage. A minimum acceptable camera shutter speed of 1/125 of a second was selected, based on the desired ability to locate vehicle positions to a precision of approximately one foot (a vehicle traveling 70 mph moves this far in about 1/100 of a second, with the result that slower shutter speeds would see perceptible smearing of vehicle images). Digital scanning at 1200 pixels per inch was expected to be close to the practical resolution of this high speed color negative film, with a 6x7 cm negative producing a digital image of about 2700x3200 pixels.

Digital scanning was quite successful. Photographic image quality was perceptibly better two hours before sunset, however the shadow of trees and buildings at that relatively low sun angle made vehicle identification difficult in some circumstances. The images recorded after sunset required the use of a slow (1/125 s) shutter speed, and were still underexposed by approximately two stops (i.e., a factor of four). In spite of the potential loss of sharpness and the underexposure, these images were perhaps more usable than the earlier ones due to the lack of shadows. This finding also suggests that imagery collected during overcast conditions may in fact be more useable than that collected under clear skies.

2.2.5 Satellite Imagery

Government and private satellites routinely take pictures of the Bay Area.

The National Aerial Photography Program (NAPP), coordinated by the U.S. Geological Survey (USGS), photographs the 48 coterminous states every five years. The NAPP photographs have an approximate scale of 1:40,000 and are flown in black-and-white or color infrared. Although Northern California is scheduled to be photographed in 1998, the LANDSAT satellite data resolution is not sufficient for counting vehicles between interchanges (one millimeter on the printed photograph would represent about 120 feet, about 6 car lengths).

At present, other remote sensing alternatives (RADARSAT and SPOT) only provide imagery with ground sample distance of approximately 10 meters.

The only satellite imagery that might be useful for measuring vehicle densities would be the 1 meter IKONOS satellite that is scheduled for launch in October of this year (1998). This data will be available approximately 80 days after launch. However, the times of day when the satellite is overhead are determined by its orbit, and, at 38 degrees latitude, the latitude of the San Francisco Bay Area, the satellite will be overhead only once every 1 to 5 days. If the time of day when the satellite is overhead is completely random, then the satellite would be overhead during either the morning or afternoon peak hour anywhere from once every 12 days to once every 60 days. It is possible to increase the number of days when pictures can be obtained by taking shots at an angle when the satellite isn't directly overhead, but this requires some maneuvering of the satellite and results in a significant loss in resolution (3 meters resolution instead of 1 meter). The costs and feasibility of scheduling such maneuvering have not been explored.

2.2.6 Accuracy

Black and white film provides 9" by 9" photos with resolutions of better than 1/1000 of an inch . At a scale of 1:12,000, an area of 9000 feet x 9000 feet can be covered by a single photo frame with an effective resolution of one foot. A resolution of one foot means that the speed of a vehicle in two pictures taken 4 seconds apart can be determined to an accuracy of 0.25 feet per second. However, knowing the vehicle speed that precisely at a particular moment in time does not mean that it will be traveling that same speed for those periods in time for which we do not have photos. Consequently the error is greater when we attempt to extrapolate the results for one moment in time to an entire peak hour.

A study for Caltrans found that the aerial photo estimated mean speeds for the peak period (2 hours) were within 1.4 mph of the floating car estimated speeds (see Exhibit 6) when time lapse photography is used. Density photography (which depends upon a calibrated speed-density equation) is less accurate, yielding mean speeds with a standard error of plus or minus 5 mph.

The much larger sample sizes possible with aerial photography however allow a better estimate of the variation in speeds on the facility than can be obtained from floating cars.

Commercial radio stations often use aerial observers to spot and report congestion, rather than taking pictures and measuring precise speeds and densities. A recent study by Dowling Associates for the Santa Clara VTA Congestion Monitoring Program compared the congestion measured off of photos taken every half hour to commercial radio broadcasts using three aerial observers that had to cover the entire Bay Area during the three hour afternoon peak period. It was found that current commercial radio traffic reports report about 25% of the actual centerline miles of freeway congestion occurring during the PM peak period in Santa Clara County. The commercial broadcasts also erroneously reported congestion (a couple of times) that did not actually exist on the ground. These errors occurred early in the peak period, when the radio station relied upon Highway Patrol reports and did not actually have its observers up in the air yet.

2.2.7 Cost Information

The costs of aerial photography data collection consists of three main components: aircraft operations; image preparation costs, and data reduction. Plane and pilot rental typically cost $150 per hour including fuel. A camera person may cost another $40 to $80 per hour. This works out to between $2 and $4 per linear mile photographed, allowing for turns and course corrections. Standard color film and film processing costs are about $0.70 per photo. It takes about 10 minutes of labor per photo to count the cars, but when set up time, training, spreadsheet entry, and processing is included, the total labor is about 30 minutes per photo when processing a couple thousand photos. Approximately 1 to 3 photos are required per centerline mile.

Digital scanning of film imagery required approximately $30 per corridor mile for the scanning itself. Acquisition of in-house film scanning capability for routine use would be expected to significantly reduce the imagery costs. Three to 4 hours of labor would be required to extract speed data for 1,000 vehicles. A key requirement for achieving these low labor costs is the development of image analysis software that facilitates recording of vehicle position, speed and roadway segment data.

2.2.8 Local and National Experience

Aerial photography is a relatively new technique for measuring vehicle speeds.

- The density photography method was used by Dowling Associates for the Santa Clara County 1997 CMP Monitoring effort. Black and white negatives were shot at 18,000:1 scale, of 151 miles of freeway for 6 peak hours and manually processed.
- Time lapse photography was used by SAI and Dowling Associates to measure vehicle speeds on freeways and arterial streets in Los Angeles and in Sacramento. Black and white photos were shot at 12,000:1 scale and scanned at 1,200 dpi into bitmaps for processing.
- Skycomp, Inc. has been doing aerial congestion monitoring of Washington D.C. and other major urban areas.

3. VEHICLE TRACING TECHNIQUES

Vehicle tracing techniques involve tracking either test vehicles or randomly selected vehicles through a network of checkpoints to determine the travel times between points. The vehicles being traced may be private automobiles, transit vehicles or trucks.

3.1 Test Vehicle (Floating Car) Technique

The test vehicle method (often referred to as floating car) has been the most common travel time collection method employed to date. This method consists of driving a vehicle along a pre-selected route and measuring the elapsed time and distance traversed.

Data collection personnel within the test vehicle control the speed of the vehicle according to set driving guidelines (i.e., average car, floating car, and maximum car), although it is usually the median travel time that is measured. In this latter case, the "floating car" is driven so that it is passed by as many vehicles as it passes during the run. The median travel time can be easily obtained from less than half a dozen runs. However, if one wishes to measure the vehicle by vehicle variation in travel time for a given route then a much larger sample size is required. The "floating car" must then make dozens of runs following a different randomly selected vehicle each run.

Travel time, speed, and delay information can be recorded in the test vehicle using varying levels of instrumentation:

- *Manual* (stopwatches, pen, and paper),
- *Electronic Distance Measuring Instrument (DMI)*, and
- *Global Positioning System (GPS) Receiver*.

3.1.1 Manual Method

The manual method requires two people per car. The passenger in the test vehicle manually records travel times at designated checkpoints using a clipboard and stopwatch. It costs about $80 per vehicle hour to collect data. The manual method does not require any significant initial capital investment in equipment, but it is difficult to control the quality of the data and the manual method does not provide information on how the speed profile varies between checkpoints.

3.1.2 Distance Measuring Instrument

The DMI (Distance Measuring Instrument) method requires that specialized equipment be purchased and installed in the test vehicle. An electronic DMI is connected by a special cable to the vehicle's transmission. The DMI is then coupled with a portable computer and specialized software to record speeds and distances traveled up to every half-second or greater. A hole must be punched in the passenger compartment for the cable (which discourages the use of personal vehicles and makes it difficult to swap the equipment out of one vehicle into another). A laptop and software are required for data collection. Typical equipment and software costs are $2500 to $8000 (depending on whether the laptop is included in the cost). The DMI must be recalibrated every time the tires are changed or the tire pressures are adjusted on the test vehicle. Only one operator is required, so labor costs are typically half those of the manual method. The DMI method eliminates data recording errors and provides speed profiles between checkpoints.

3.1.3 Global Positioning System

The GPS (Global Positioning System) method requires that specialized equipment be purchased and a receiving antenna be installed in the test vehicle. A GPS receiver coupled with a portable computer is used to record the test vehicle's position and speed at time intervals as frequent as every second. Equipment costs are lower than DMI (ranging from $4500 to $6500 per vehicle), but there is an annual subscription fee of about $1000 per year per vehicle to receive the decoded satellite signal. GPS signals can be lost in urban canyons, under trees, or around power lines. Signal loss used to be a frequent problem with GPS, particularly at the start of the run, when several data points were lost until the GPS receiver successfully achieved its first fix. The launching of additional satellites have reduced data loss, although it is still typical to lose about 1% or less of the data points due to signal loss. Post processor software and manual intervention are required to fill in the missing points. Post processor software (or manual adjustment of the GPS data) is also required if it is desired to plot the GPS routes on a map, because the accuracy of the map does not approach that of the GPS points (The GPS route when plotted on a Census Tiger File map will often look like it was on an adjacent parallel street.)[6]. Compared to DMI, GPS has the disadvantage of missed data points, but the advantage of not needing recalibration every time the tires are changed. GPS equipment is also more portable between vehicles.

3.1.4 Accuracy

GPS units have two inherent sources of error. One is a random "dithering" of the latitude and longitudes introduced by the Department of Defense to reduce the utility of the GPS system for foreign powers. By standing at one point for several minutes and taking several readings one can compensate for this "dithering" error by taking the average of the readings. This kind of error though is usually not significant for travel time measurement purposes. The other source of error is the generally lower accuracy with which traditional maps are prepared. Map latitudes and longitudes do not usually correspond well to GPS coordinates. This error can be significant, causing a vehicle to appear to be on a parallel street. The means of correcting for this is for the observer do a preliminary "calibration" run noting the street name and intersection names every so often, simultaneously with the GPS latitude and longitude. Then the GPS readings can be translated to map locations using the intersection names.

The mean median speed (measured over the entire length of the run) can usually be obtained to within 1 mph with 95% confidence with between half a dozen and a dozen runs. Measuring the speeds of individual vehicles (car following) however requires much larger sample sizes to compute reliable mean speeds and variances.

The median speed is the speed at which 50% of the cars are going faster and 50% of the cars are going slower. The mean of the median, therefore, is what is measured when several floating car

[6] One technique for controlling for this mapping problem is to do a GPS calibration run where the vehicle remains stationary for a couple of minutes at each intersection and the intersection name and GPS coordinates are noted by the data logger.

run results are added together and averaged. The mean and the median speeds should be pretty close for most normal distributions of vehicle speeds.

3.1.5 Cost Information

Typical costs for floating car methods are summarized Exhibit 8. GPS and DMI can cut data collection costs in half by eliminating the need for a passenger in the vehicle.

Labor costs and vehicle availability generally limit the size of the samples that can be obtained at any one time by the test vehicle method. The purchase and installation costs of DMI and GPS equipment also limit the number of test vehicles that can be operated at any one time. Data reduction effort is much higher for GPS than for manual recording, but the quality and quantity of the data is quite a bit greater when using GPS.

Exhibit 8. Costs for Floating Car Methods

Method	Equipment Costs	Labor Costs	Data Reduction Costs	Other Costs
Manual	$5/vehicle (for clipboard)	$80/hr (driver plus recorder)	low	none
DMI	$2500-$8000/vehicle (for DMI, software, laptop)	$40/hr (driver only)	medium	none
GPS	$4500-$6500/vehicle (for receiver, software, laptop)	$40/hr (driver only)	high	signal subscription

3.1.6 Local and National Experience

Agencies using the manual test vehicle method are too numerous to include here.

Several agencies are currently using electronic DMI's:

- Caltrans - used floating car methods to monitor congestion. Surveys performed for the duration of congestion, and includes a twice a year comparison of HOV to mixed flow lanes. Contact Albert Yee, Caltrans 04.
- Santa Clara VTA - This local agency has purchased a DMI which it makes available to consultants hired to perform its annual CMP monitoring program.
- Texas Transportation Institute - use in Houston and Dallas-Ft. Worth for HOV lane evaluations, congestion monitoring, activity center and regional travel time studies, modeling and other planning. Also developed CATS reduction/analysis software. Contact Robert Benz, TTI, (713) 686-2971.
- Hampton Roads Planning District Commission - use for regional travel time study, travel time contours, and congestion management system. Contact Mike Kimbrel, HRPDC, (757) 420-8300.
- City of Austin/Austin MPO - use for congestion management system and signal re-timing evaluations. Contact Scott Feldman, City of Austin, (512) 499-7230.

Several agencies are currently using GPS for travel time studies:

- Kimley-Horn recently used GPS equipped vehicles to measure mean segment speeds for all of the signalized arterials in the City of Palo Alto.
- Baton Rouge MPO - use for congestion management system. Contact Darcy Bullock, Purdue Univ., (765) 494-2204 or Cesar Quiroga, LSU, (504) 388-5260.
- Texas Transportation Institute - use for supporting Model Deployment Initiative and NHTSA studies in San Antonio, also congestion management system. Contact Jennifer Ogle, TTI, (210) 731-9938.
- Sacramento COG - use for congestion management system and other planning activities. Contact Bruce Griesenbeck, SaCOG, (916) 457-2264.

3.2 Non-Instrumented Vehicle Tracking Technique

This technique uses any one of several technologies for identifying randomly selected un-instrumented vehicles in the traffic stream at various checkpoints within the study area and measuring the time between appearances at each checkpoint. Vehicle tracking is different than using a test vehicle, because the driver has not been hired to do the study. The driver drives his or her normal route without reference to the desires of the public agency to test a particular route or time of day, an the vehicle itself does not possess any special instrumentation to aid in identifying the vehicle.

Technology variations for tracking vehicles include license plate matching, license plate matching with video OCR, and loop detectors with vehicle signature matching.

3.2.1 License Plate Matching

The license plate matching method consists of collecting vehicle license plate characters and arrival times at sequential checkpoints, matching the license plates between checkpoints, and computing travel times from the difference between arrival times at checkpoints.

License plate matching has been used by relatively few transportation agencies for travel time data collection, even though license plates are commonly collected for origin-destination and through traffic surveys. Potential reasons for this low use may include the difficulty of reading full license plates at highway speeds, recording arrival times using manual methods, or the inability to control those vehicles providing the travel time data. Portable computers and video cameras have made the license plate matching method attractive to several transportation agencies for specific studies, most notably high-occupancy vehicle (HOV) lane performance evaluations that compare travel time variability between HOV and general-purpose lanes.

License plate matching for travel times can be performed with varying levels of instrumentation.

The manual method involves the use of pen and paper or audio tape recorders to record license plate characters, then later transcribing the license plates into a computer for subsequent matching. Time stamps must be recorded in the field when using pen and paper. Computer time stamps can be used to estimate vehicle arrival times with the audio tape recorder if the tape is transcribed at regular speed.

Portable computers might be used in the field to assist human observers in recording and later matching license plates. Time stamps are automatically provided by the computer for each license plate. Voice recognition software has been tested to improve the ability to input license plate characters in the field.

High speed video cameras or camcorders can be used to collect video images of license plates. Video recordings are often used when the speed and volume of traffic is too great for accurate manual recording of license plate numbers. The video is then reviewed at a lower speed and manually transcribed at a later date.

3.2.2 License Plate Matching With OCR

Character recognition software may be used to reduce the labor costs associated with the manual transcription of license plate characters from the video recording for subsequent computer matching. Numerous vendors in the U.S. and elsewhere sell automated license plate readers (LPR's) and several vendors offer travel time data collection services. Although the technology is still developing, the license plate read rates being obtained by several vendors (between 40 and 80 percent) can still provide significant travel time and travel time variability data. Manual review of license plates not recognized by the computer software can be used to increase the license plate read rate. The Minnesota and Washington State Departments of Transportation (DOT's) are testing the use of video cameras and LPR's to provide real-time travel time information.

3.2.3 Vehicle and Platoon Signature Matching

Several agencies are studying the use of vehicle signature matching and platoon matching to obtain travel times over lengths of freeway. Vehicle signature matching calculates travel time by matching or correlating unique vehicle signatures between sequential observation points. Vehicles with unique signatures among passenger vehicles include large trucks, buses, and various truck/trailer combinations.

Platoon matching uses similar concepts, except that this method correlates the number of large vehicles within a vehicle platoon between two consecutive locations.

Vehicle signature and platoon matching avoid the potential "privacy issues" of some probe vehicle systems that could potentially be misused to identify the owners individual vehicles. Some researchers also see vehicle signature and platoon matching as implementable in the near term with existing traffic surveillance infrastructure.

3.2.4 Accuracy

Samples of 100 vehicle matches per pair of checkpoints should be quite sufficient for determining both mean travel time and variance to within 1 minute with 95% confidence. The length of the survey period and the number of vehicles that must be recorded to achieve the desired sample size will be determined by the percentage of vehicles passing through both checkpoints. Obviously, license plate matching becomes very cost ineffective when the percentage of through vehicles drops below 10%.

3.2.5 Cost Information

License plate surveys run about $600 to $800 per hour per pair of checkpoints per lane of freeway surveyed. The majority of this cost is the cost of data reduction (manually reviewing the videotape, manually recording license plate numbers, and applying license plate matching software).

Equipment costs include several thousand dollars for specialized high speed video recording and playback equipment. The playback equipment must have relatively high quality freeze frame or slow motion playback capabilities.

Labor costs include the time spent viewing the tapes plus the cost of a trained camera operator to set up, monitor, and take down each checkpoint camera. Equipment set up at street level must be continuously monitored to avoid theft. However, even the presence of an operator has not always prevented thefts in the past (e.g. a contract operator was severely injured during an armed robbery in Fresno).

To the extent that loop detectors are already in place for other purposes (such as incident detection and ramp metering), there are no additional equipment costs associated with this technique (beyond the acquisition of the necessary software and data storage capabilities). It would cost about $12,000 per station (with a minimum of two stations required) to install loop detectors for the sole purpose of vehicle signature matching. Additional maintenance costs would also be incurred. (See chapter on spot speed measurement techniques.)

3.2.6 Local and National Experience

Several agencies have experimented with or are using portable computer-based license plate matching:

- Washington State DOT - used for HOV lane evaluations, experimented with voice recognition. Contact Mark Hallenbeck or Nancy Nihan, TRAC, (206) 543-6261.
- Chicago Area Transportation Study (CATS) - used for regional travel time study, but abandoned in favor of manual test vehicle method. Contact Ed Christopher, CATS, (312) 793-3467.
- Texas Transportation Institute - experimented with method but opted for DMI test vehicle method, also developed license plate collection and matching software. Contact Shawn Turner, TTI, (409) 845-8829.

Numerous agencies have used video with manual transcription.

- MTC used video with manual transcription to record licenses for the I-580 Altamount Pass External Trip Study. However, this was for the purpose of identifying residence locations, not for measuring travel times.
- Caltrans hired a private contractor to record and match licenses at a pair of checkpoints for the Oakdale Route 120 Bypass EIR. High speed video cameras were used along with manual transcription. The data however was used to determine the percent of through traffic, not to measure travel times.

Agencies that have used or are experimenting with video with automatic LPR's (license plate readers) for travel time are:

- Washington State DOT - contracted with vendor for LPR data collection services, also experimenting with real-time LPR at the Canadian border. Contact Kern Jacobson or Mark Bandy, WSDOT, (206) 440-4477.
- Hillsborough County (Tampa) MPO - demonstrated LPR technology for congestion management system. Contact Mike Pietrzyk, Center for Urban Transportation Research (CUTR), (813) 974-9815.
- West Virginia DOT - experimented with developing and using LPR equipment. Contact James French III, West Virginia University, (304) 293-3031.
- Transport Agency in the United Kingdom - is installing approximately 3,000 video cameras over 6,000 miles of roadway to capture video and automatically read and match license plates.

Mr. Jeff B. Woodson (jeff@transfo.com) and P.W. Shuldiner have jointly and separately written several papers on the use of automated license plate readers to obtain travel time information. M.C. Pietryzk, of the University of South Florida, has also done some research on video-based traffic data collection.

Information on recent vehicle signature tracking research can be obtained from Mr. Benjamin Coifman, Ph.D. candidate at the University of California, Berkeley, (510-642-3585, direct line 642-9907). He is currently completing his dissertation on "Vehicle Re-identification and Travel Time Measurement on Freeways Using Simple Vehicle Signatures".

3.3 Passive Probe Technique

The passive probe technique tracks transponders of some kind that have been placed in a subset of the vehicle fleet. The vehicles are called passive probes because the drivers have not been hired to participate in the data collection effort (thus they are passive) and not all vehicles are instrumented with transponders (thus making them probes for the entire vehicle fleet). Vehicle drivers go about their regular business and the transponders are used to follow all or portions of their trips.

Passive probes are divided into two basic technologies, roadside tracking and areawide tracking, depending upon the method used to track the vehicle transponders. Roadside tracking includes signpost based, emergency pre-empt, and automatic vehicle identification technologies. Area wide tracking includes cellular phone and GPS tracking technologies. Area-wide tracking is not limited to the particular locations where roadside sensors are placed.

3.3.1 Automatic Vehicle Location

Automatic vehicle location (AVL) systems rely on transponders attached to roadside signposts and a receiver on the vehicle to determine when the vehicle passes a pre-set point. The roadside transponders tell the vehicle its location as it passes by the check point. The information is stored on the vehicle and may be transmitted to a central monitoring station.

3.3.2 Advanced Vehicle Identification (AVI) Systems

The Advanced Vehicle Identification (AVI) system uses a combination of electronic tags on board of a private or publicly owned vehicle, and roadside readers to track vehicles along a given roadway or transportation link. A centralized system then matches the tagged vehicles and calculates a series of roadway conditions, including vehicle speeds and travel time.

The Advanced Vehicle Identification (AVI) system is comprised of three components.

The first component of the AVI system is an electronic identification tag or transponder that is placed in a vehicle. Electronic Toll Collection (ETC) transponders can serve this purpose, as can other types of electronic tags. The tags can be installed in public agency, transit, or private vehicles.

The second component of an AVI system is the reader that is placed along the corridor, between 1 to 5 mile increments. Typically, the readers are installed under bridges, on sign trusses, on overhead structure, or on a pole for side fire detection. Each reader has a “capture zone” 100-200 feet wide with the new generation of tag readers. The tag readers can communicate with several vehicles at one time, allowing tracking of multiple vehicles in a given segment. Each reader transmits the collected data via wireless mediums to a hub location, which in turn transmits the information to a central processing station through leased phone lines or wireless mediums. At the central processing center, when a vehicle’s tag is detected, the system then anticipates receiving a signal at the next reader station downstream The system then matches the transponder information between two stations and calculates the travel time along the corridor.

The third component of an AVI system is the data processing. The mean travel times and speeds along with the associated standard deviations, can be calculated for every 15-minute intervals. Travel times and average speeds can be saved in the categories of weekdays, Saturdays, Sundays and holidays.

A customized AVI system might be used to track vehicles by vehicle type.

3.3.3 Emergency Vehicle Passive Probe Systems

Emergency vehicle pre-empt systems may be adapted to act as probe vehicle systems. An Emergency pre-empt system typically consists of an emitter unit and a discriminator module. The emitter unit, installed in an emergency vehicle, sends out a continuous optical signal that is intercepted by a discriminator module, typically installed on a traffic signal mast arm. This allows the emergency vehicle to pre-empt the traffic signal.

A special non-pre-empt emitter can be mounted on any vehicle, including publicly or privately owned vehicles. Once the vehicle’s emitter signal is intercepted by the discriminator unit, the system will log the arrival time and the vehicle’s emitter identification code without pre-empting the signal. Once the arrival time is stored, the information can be downloaded on a routine basis for analysis.

3.3.4 Cellular Phone Tracking/Geolocation Systems

Geolocation techniques can provide a relatively inexpensive and accurate method for estimating traffic conditions over a region. The geolocation technique automatically detects phone call initiation, and will locate a given vehicle within a few seconds. After it has determined that a vehicle is on a roadway of interest, the system will periodically plot the vehicle's location to determine its speed and travel distance. It will average the speeds of numerous vehicle on a give roadway and can automatically estimate the travel time along a given corridor, during a given time period.

A two-year experimental project in the Washington D.C. area, known as the Cellular Applied to ITS Tracking and Location (CAPITAL), has developed operational field tests of the geolocation system. This project was based on a partnership between the U.S. FHWA and several public and private participants. The operational test has shown that geolocation system can be an accurate method for estimating traffic conditions, travel times and speeds over a given region.

Another method for using the cellular phones is the manual check-in. Volunteers or public employee agencies can check-in at regular intervals during their normal work trips to establish location and speeds. Cellular phone reporting is used in several regions as part of traveler information services.

The geolocation equipment is based on technology previously developed by Raytheon E-Systems for other U.S. Government applications. The geolocation components consist of Transmission Alert System (TAS), Direction Finding Systems (DFS) and the Geolocation Control System (GCS). The TAS looks for vehicles initiating phone calls by processing the cellular reverse control channels (phone-to-tower) and identifying when a mobile phone transmits a message. At the same time, the forward control channel (tower-to-phone) is examined for the assignment of communication channels to the mobile phones. This information is combined to produce a Call Initiation message for a phone. The geolocation components then uses directional finding equipment located at multiple sites throughout the geographic area of coverage to determine the position of the probe vehicle by triangulation and time-difference-of-arrival techniques. The triangulation method uses intersection lines of bearing, derived from the direction of radiation from a mobile phone, to determine the probe's location. The time-difference of arrival method calculates the location based on the signal propagation times between the vehicle and nearby cellular towers. The position of the probe is then passed to the Traffic Information module. By repeating this process every five to seven seconds, sufficient data is generated in 30 to 50 seconds to provide an accurate estimate of the vehicle's velocity and travel path during the call.

Data processing for the CAPITAL geolocation system is performed by the MIST system. The traffic data, once collected, is transmitted to an Operations Center. The system then processes probe vehicle speed data and cellular call activity statistics. Data fusion techniques can synthesize real-time estimates of traffic conditions from raw speed data and historical speed profiles. Profiles can be stored for each roadway link by time of day and day of week. The system can also generate statistical data produced by the geolocation system.

Triangulation techniques can also be applied to locate radio transponders on vehicles and are used in route guidance and personal communication systems. This service is only available in limited markets. Telegram, Inc., for example, currently offers vehicle location services in nine U.S. cities:

Los Angeles, San Francisco, San Diego, Sacramento, Detroit, Chicago, Dallas/Ft. Worth, Houston, Orlando, Miami and Washington, D.C./Baltimore.

3.3.5 Global Positioning Satellite (GPS) Systems

The general concept of the GPS system is to use a GPS receiver and a laptop computer to record trips while traveling along a transportation corridor. The GPS unit will collect latitude, longitude, time and velocity information at one or two second intervals. The data can then be downloaded to a database program for processing.

The Global Positioning Satellite (GPS) system is a $13 billion program sponsored by the U.S. Department of Defense (DOD). The system was deployed primarily for military applications, but it is available to all users. The system can provide accurate position and time, 24-hours a day, anywhere in the world. The GPS receivers, such as Trimble Navigation and Magellan, use the signals from multiple satellites to calculate latitude, longitude, altitude, time and velocity. Most receivers can update this information once per second.

The GPS receiver needs to have an unobstructed view of at least three or four satellites. Tall buildings, dense tree cover and underpasses or tunnels can interrupt the signals. The quality of positional information is also affected by the Selected Availability (SA). The DOD intentionally builds random errors into the signals that are available to the general public for security reasons. Currently the DOD provides an accuracy level of 70-meters, but there is significant pressure to eliminate the Selected Availability. If the SA is removed, the accuracy can improve to ± 10 meters. The SA can be reduced substantially by two methods. The first method employs a real-time differential correction technique that will improve the accuracy to ± 5 meters. The real-time differential correction technique is available through a FM radio receiver that can be purchased for an annual fee of approximately $900. A radio antenna will be attached to the GPS receiver, which will receiver "corrected" data, on a continuous basis. The second method employs a post processing method. In a post-processing method, the data collected by the GPS receiver can be normalized to ±5 meters by applying correction factors from another GPS receiver that has collected data, during the same time period, at a known survey point. The post-processing method is available free of charge from the U.S. Coast Guard and from other commercial vendors, such as Trimble Navigation. The accuracy of the GPS unit after post processing or real-time processing can be improved to sub-metric level, i.e. ±1 meter using the more advanced GPS receivers.

The use of GPS system for continuous travel time data collection will require a formalized data collection and reduction process. A formalized data collection process will tie the GPS system to a Geographic Information System (GIS) system. A vector map will be used to link the travel time with the GPS data. One way to obtain a vector map of the study links is to travel the corridor and obtain GPS data once every second. Once that data is collected, a vector map of the area can be developed. With the network broken into reasonably spaced segments, a relational database can be deployed to match vehicle times for each travel link. The data can then be summarized and stored for each link, for given time periods.

3.3.6 Accuracy

The Houston AVI Tag project has found that only 2 to 3 vehicle matches are required in a 15 minute period to obtain travel times within a 10% error with a 90% level of confidence[7].

The initial findings from the CAPITAL project (geolocation system) showed location accuracy in the 500-meter circular error probability (CEP) range, but through algorithm and network modification, the accuracy has improved to 115-meter CEP range. In operation, the CAPITAL system yielded significant traffic information, with a steady stream of probe vehicles, and with speed data accurate to ±5 mph. Test data showed that geolocation of only 5 percent or less of the vehicles on a given link provided sufficient data to estimate average link speeds with a high degree of confidence. Although, the CAPITAL project has shown that the geolocation can be an accurate method for estimating travel speeds, more studies should be conducted to evaluate the travel time results and the accuracy of the information.

The AVI system accuracy is dependent on the sample size. Given a sufficient number of matched vehicles, space mean speed and travel times for any given link can be established. However, having a sufficient sample size is dependent on having sufficient number of vehicles with transponders and an adequate number of readers. An analysis of the accuracy of the data for the TRANSMIT project showed that 85% of the tagged vehicles were identified within the system, with the best matching during the AM and PM peak hours. Since the number of vehicles with transponders decrease during non-peak periods, the accuracy of the system is also reduced between 9 a.m. to 3 p.m. This is explained by the fact that many of vehicles equipped with the AVI transponders are driven by commuters who travel predominantly between hours of 6 a.m. – 9 a.m., and between 3 p.m. and 6 p.m.

Using statistical analysis methods, the TRANSTAR project found that a minimum of thirty probe vehicles are required in order to provide a sufficient sample size for a given time period. In an arterial corridor, the level of accuracy will decrease because of the more and closer spaced access points. Having more reader stations at shorter intervals can compensate for this problem. An AVI system is very reliable when fully deployed and operational.

GPS systems can be fairly accurate and reliable. One of the problems with the accuracy of a GPS system is the Selective Accuracy discussed above. The Boston Central Transportation Planning Agency conducted a test of accuracy of GPS versus manual travel time methods. Using the GPS equipment, travel time data was collected on the southern section of Route 128 for the PM peak hour period. The Boston project did not normalize the data using either the real-time or post processing differential correction techniques. The results of the study showed that the differences in distance were less than 0.1 mile and speeds within ±5 mph. The conclusions of the study were that the GPS method could yield as accurate data as manual methods. Although, the Boston study recommended that differential correction is not necessary for the required accuracy, the overall accuracy can be improved with the application of differential correction techniques.

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[7] Source: Dr. Tim Lomax, Texas Transportation Institute.

Because the probe vehicle method does not rely solely on trained agency drivers to collect data, travel time sample sizes potentially can be much larger than those obtained from the test vehicle method.

3.3.7 Cost Information

Most probe vehicle systems rely on an extensive electronic and communications infrastructure. In some cases, however, this infrastructure may already exist (e.g., GPS or cell phone tracking) or be planned as a regional ITS element (e.g., AVI). Existing or planned infrastructure may weigh heavily on the decision to use certain types of probe vehicle systems.

MTC is upgrading the GPS/AVI capabilities in its FSP (Freeway Service Patrol) trucks, and will track their speeds and travel times as they cruise/patrol between incidents. The Freeway Service Patrol covers 155 centerline miles of freeway with 50 tow trucks.

A full pre-empt system for a typical traffic signal installation is between $8,000 to $10,000, including wiring and equipment. If a signal is already equipped with a pre-empt module, the additional cost will include a Model 752 Opticom Card for $1,600. The emitters for probe vehicles are $1,200 each. The central processing system is about $5,000 for software and hardware. However, if there are no communication links between the central system and the local traffic controllers, the cost for completing the link could be high. For a wireless spread spectrum option, the cost is between $8,000 to $10,000 per intersection.

No exact figures are available for system costs for a geolocation system. The CAPITAL project estimates that a geolocation system can cost approximately one-seventh of the magnitude of a comparable loop-based system. Approximate cost for software development and system implementation can range between $1 to $2 million.

The cost of an AVI system will include both the capital and the on-going maintenance costs. Capital costs include reader stations, communication links, central system processing computer, and software development. One of the biggest start-up costs is the communication link between the reader stations and the central processing center. Different technologies can be used to establish this link, including wireless and landline options. Wireless technologies include spread spectrum, radio, analog cellular, personal communication services (PCS), cellular digital packet data (CDPD), and satellite systems. Landline options include fiber optics and leased-phone lines. Wireless options are typically more feasible between the reader stations and the hub locations - with hardwired connections being more feasible between the hub locations and the central processing center. Spread spectrum systems, such as Metricom in the Bay Area, can be a very a cost effective option for establishing the links between the reader stations and the communication hubs. Spread spectrum radio can range between $500 to a $1,000 per site, with a monthly charge of $30 to $50 per site. The communication hub location cost can range between $10,000 to $20,000, depending on the complexity and amount of data links. The cost of the reader sites range from $20,000 to $50,000. Software development, set-up and central computer systems can range between 1 to 2 million dollars.

GPS receivers are fairly inexpensive in comparison to other data collection equipment. Currently, the typical cost of a GPS receiver is between $500 to $5000, depending on the features. One of the important factors in a GPS receiver should be the ability to download information with a PCMCIA interface to a laptop computer. Laptop computers can range between $2,500 to $3,500. Other features of the system may include the Personal Digital Assistant (PDA) that can range between $500 to $1,500. For a real-time differential processing service, the charge is approximately $900 for an annual subscription. The post processing technique is free from Trimble Navigation or the U.S. Coast Guard. For routine data collection, a GIS based database design will help with data reduction. Setting up a GIS based centerline system for the Bay Area CMA system may range between $200,000 to $400,000. A system using an Oracle relational database may cost between $250,000 to $500,000 for the entire Bay Area network.

3.3.8 Local and National Experience

Many transit agencies in the U.S. currently use signpost-based automatic vehicle location (AVL). Two recent reports provide comprehensive documentation: TCRP Synthesis 24, AVL Systems for Bus Transit by Paula Okunieff of Cambridge Systematics and SWUTC Report 30060-1, Evaluation of Automatic Vehicle Location Systems in Public Transit by Katherine Turnbull, TTI, phone (409) 845-6001.

A limited number of AVI probe vehicle systems currently exist in the U.S.:

- Texas DOT/TranStar in Houston - This project includes an AVI element as part of Houston’s Traffic Monitoring System, which currently includes 227 miles of freeway and 70 miles of HOV lanes. This AVI probe vehicle system has been in operation since 1994, covers most of the freeway system in the Houston area, and has an AVI tag base near 200,000 in the region. Utilizes Oracle’s database system for data matching and processing. Contact Carlton Allen, TxDOT, (713) 881-3000 or Dick McCasland, TTI, (713) 686-2971.
- Texas DOT/TransGuide in San Antonio - This AVI system will officially begin operation in June 1998 when the Model Deployment Initiative is formally completed. Approximately 20,000 tags have been distributed to volunteers because no electronic toll collection facilities exist in the San Antonio area. Contact Steve Dellenback, Southwest Research Institute, (210) 522-3914.
- TRANSMIT in New York - This system has been operational for several years and relies on widely-distributed EZ-Pass tags approved by several toll agencies in the New York-New Jersey region. Initially, the vehicle probe system was recommended for a 19-mile segment along the Garden State Parkway in New Jersey and I-287 in Newark and was deployed by the New York State Thruway Authority as a part of the Electronic Toll Collection (ETC) system in 1993. However, currently the system has expanded to cover most of the 495-mile thruway segment. When fully implemented, readers will be installed along toll facilities throughout New York, New Jersey, Pennsylvania and Delaware. Utilizes Oracle’s database system for data matching and processing. Contact Matt Edelman, TRANSCOM, (201) 963-4033.
- Spokane MPO - This MPO is conducting tests of AVI technology in an off-line manner. Tags have been distributed to volunteers and data are downloaded on a weekly basis from roadside controller cabinets. Contact Pam Tsuchida, Spokane MPO, at (509) 625-6370.

Limited tests of cellular phone tracking and ground-based radio navigation for travel time collection have been conducted:

- The CAPITAL operational test in Washington, D.C. - Cellular phone tracking was tested with relatively successful results (contact Robert Larsen, Raytheon E-Systems, (703) 560-5000).
- Dade County MPO - CUTR conducted tests of ground-based radio navigation for collecting congestion management system data. Contact Mike Pietrzyk, CUTR, at (813) 974-9815.

The use of GPS in probe vehicles has several real-time and off-line examples:

- ADVANCE - This operational test in the northwest suburbs of Chicago originally called for several thousand probe vehicles equipped with GPS, but eventually used about 50 probe vehicles. Contact Joe Ligas, Illinois DOT, (847) 705-4800.
- Lexington MPO - FHWA and Battelle worked with the Lexington MPO in testing GPS for personal travel surveys. Trip time information was one of many elements gathered from the GPS and personal digital assistant. Contact Elaine Murakami, FHWA, (202) 366-6971.
- Texas DOT in Austin - The Austin district is planning to use GPS receivers to log trip and travel time information in a household travel survey. Approximately 50 of the units will be distributed to commuter volunteers. Contact Ken Mora, TxDOT, (512) 486-5135.
- FHWA - Is considering the collection of travel time data as a part of travel diary surveys. Participants in this project will be given a Personal Digital Assistant (PDA), connected to a GPS receiver to record their typical trip data. Contact David Roden, TransCore, (703) 288-8388.

3.4 Transit Vehicle Tracking

The previous sections have described various techniques for tracking vehicles in general. This section discusses the issues of specifically tracking transit vehicles alone.

First, MTC and other agencies have the option of using any of the previously discussed vehicle tracking techniques (license plate matching, passive probes, etc.) to track transit vehicles. The only difference would be the need to negotiate with the transit operator for permission to place any transponders or data recorders in the transit vehicles and to arrange for their security and operation.

The second option is to obtain the transit travel time information the transit operators already collect. MTC might seek to obtain the raw travel time data for individual transit vehicles (potentially a massive amount of difficult to process data), or MTC might rely instead on a combination of published schedules and operator on-time performance results.

Transit schedules might be obtained electronically from MTC's TRANSTAR database. TRANSTAR is an integrated regional database of transit information (currently under development) that consists of three major types of information: time points of each route, route patterns showing the intersection of routes of different transit operators, and fare information.

3.4.1 Transit Travel Time Monitoring Techniques

Transit operators use several methods for tracking transit vehicle travel times, including:

- Point Checks;
- Ride Checks;
- Signpost System (AVI/AVL); and
- Global Positioning System (GPS).

Point checks are a very common way for transit agencies to collect transit performance data. A point check requires that a transit employee called a checker stands at a specified location along a transit route and records the time, direction, and identification number of each bus (or other transit vehicle such as light rail) that passes that given point. The recorded data is then compared to the assigned schedule for the given bus. This is a very labor intensive process, even for small to moderately sized transit systems, considering the potentially large number of check points required for surveying.

Ride check surveys are similar to the point check surveys. Checkers or surveyors manually record data on field form reports or using palm-top computers. However, the purpose of the ride check survey is different than the point check. It is implemented to collect travel time and other data about an individual bus (or other transit vehicle) run from the first to the last terminal location associated with the given route. Checkers or surveyors also ride the given bus or transit vehicle under study and record the location and time of each stop. Checkers also record the number of passengers boarding and alighting at each stop. This is also a very labor intensive process.

The **signpost system** for Advanced Vehicle Information (AVI) requires buses to be equipped with transponders that communicate with receivers mounted along the bus route using a low power radio signal. These receivers are usually mounted on utility poles or signposts. As a bus passes a receiver, it alerts the receiver of its presence, and then transmits its own unique identification number through the receiver. The receivers notify the control center at regular intervals (usually every one to two minutes) of any buses that have passed their signpost location.

Advanced Vehicle Location (AVL), places the transponder on the utility pole or signpost and the receiver on the bus. The receiver records which transponder (signpost) it passes, the time the bus passed it, and the odometer reading at the time of passing. The bus transmits this information at regular and frequent intervals to a central location. Based on the time of receipt and the average speed of the bus, the control center can estimate the location of the bus. This arrangement allows the system to report a more precise location for each vehicle, but also requires the use of dedicated radio frequencies since the receiver is mobile (i.e., on the bus).

Global Positioning System (GPS) technology is a satellite-based AVL system. A receiver installed on the top of each bus reads signals from satellites to identify the bus' coordinates on the earth's surface. The bus then transmits this location data to the central control center. GPS can provide fairly accurate location data regardless of whether buses maintain their routes or not, and can operate in urban and rural environments as long as there is direct communication with at least three satellites. Tunnels, tall buildings, and heavy foliage can interrupt this communication. When these obstacles exist, GPS can be supplemented by other location technologies such as signposts or dead-reckoning.

3.4.2 Current Transit Vehicle Monitoring Capabilities in Bay Area

As part of the field test for this project, the consultant surveyed a number of large transit operators in the Bay Area. The objective was to determine the approximate range of data available and the range of practices employed by regional operators without surveying each of the 26 operators. The operators surveyed include: BART, AC Transit, San Francisco Muni, Golden Gate Transit, and Santa Clara Valley Transportation Authority. The results of the field test are summarized below. (More detailed information may be found in the Task 7 Report.)

Most transit operators in the Bay Area use a combination of ride and point checks to monitor system performance. BART and Napa Valley Transit are the exceptions, being able to automatically monitor vehicle operations on a real time basis.

3.4.2.1 Bay Area Rapid Transit (BART)

BART generates a daily operations performance report that tracks schedule adherence, using data collected automatically by the train control system. This report provides a performance summary of the entire BART system and also lists when and where delays occur, as well as the duration and cause(s) of the delays. While this report provides management with a macroscopic perspective of system performance, another report called "Detailed Train Run Histories" is generated to provide the details of each delay for further investigation.

A report similar to the "Detailed Train Run Histories" can be produced for each train run. These reports are generated in travel time matrix format and can be produced without too much additional work, since the data are already available and the software (TMAP) used to generate the reports is a fairly user-friendly Windows-based application.

Published schedules are updated when there are major service changes, such as the Colma extension.

BART considers a train to be on-time if it arrives at a station within five minutes of the scheduled time. BART maintained 92 to 94 percent of its trains on-time during the first six months of 1998.

3.4.2.2 Alameda-Contra Costa Transit District (AC Transit)

AC Transit is experimenting with GPS but currently relies upon point and ride checks to monitor its performance. Data on schedule adherence are collected quarterly. Point checks are conducted to collect sample data at thirteen predetermined locations comprising a sample of thirty-three bus lines. Observations are recorded manually. The same locations are used every quarter in order to maintain reporting consistency. All bus runs at these thirteen locations are observed and recorded manually for a predetermined day of the week within a predetermined week of a quarter.

At the system level, approximately four thousand bus runs are recorded every quarter. The number of bus runs recorded varies from route to route. For example, a total of 163 bus runs were observed for route 51 while only 34 runs were recorded for route 14 for a study completed in 1997. The number of bus runs observed for each route is largely determined by the frequency of service.

Data are presented by route and time points and are stored by AC Transit technical staff using Microsoft Excel Spreadsheet software. Analysis is performed at both the system and route levels. Changes in transit service are stored in what is called a "line file", which is a text file. This line file also stores almost every piece of information related to each route, from headways to complaints received from patrons.

Schedules are adjusted every quarter to reflect changes in transit service. Minor revisions to schedules are made each quarter. Major revisions occur annually.

AC Transit considers its service to be on-time if the transit vehicle is never early or no more than five minutes late when compared to the given printed bus schedule. At the system level, AC Transit has maintained an on-time performance of about 80 percent during the first two quarters of the fiscal year 1997-1998. However, the performance varies quite significantly from route to route. While some routes are on-time 90 percent of the time others are on-time only 60 percent of the time.

3.4.2.3 San Francisco Municipal Railway (Muni)

Muni relies upon ride checks and point checks to monitor its performance. Muni conducts two types of on-time performance checks:

- baseline checks; and
- terminal recovery checks.

The first type is a typical ride check performed for every bus/light rail vehicle run of every route on a sampled weekday. These ride checks are conducted on a regular basis. Muni tries to perform regular schedule adherence monitoring at five-year intervals. However, due to lack of resources, this monitoring has been performed at ten-year intervals.

The second type is a point check performed at the terminals of selected routes on an ad-hoc basis. This check is only performed when deemed necessary, and in most cases, it is conducted when Muni receives a significant amount of complaints regarding the service of a specific bus or light rail line. Observations are recorded electronically through hand-held computers.

While the goals of the two checks are the same, two different indicators of on-time performance are used. When the comprehensive baseline check is performed, the number of observations that are considered on-time (arriving within two or three minutes of scheduled time) is compared with the total number of observations recorded. Although records for individual routes are stored, on-time performance is measured only systemwide. Retrieval of data for individual routes is not regularly performed, and therefore, route data cannot be generated cost-effectively.

In the “terminal recovery check,” the times the transit vehicle arrives and departs a terminal location are recorded. The difference between the two is considered the dwell time. The schedule adherence indicator is computed as follows:

[(Scheduled Dwell Time - Observed Dwell Time) / Scheduled Dwell Time] * 100%

The schedule adherence data are stored and analyzed using RUCUS, a software developed for Muni. RUCUS is a FORTRAN-based software system that is used to convert data into ASCII format for import into widely-used Windows applications, such as Excel, Quattro Pro, etc. So, theoretically, it would be possible to obtain datasets from MUNI and process them in-house to obtain the required travel time information. However, given that a comprehensive schedule adherence study is performed about once every ten years, the usefulness of these data may not warrant the implementation of this processing task.

Schedules are revised on a quarterly basis to reflect changes in routing, headways, number of stops, location of stops, etc. for a number of bus routes/light rail lines. A major revision is performed once a year.

Using the schedules alone to compute travel time between two points of a Muni system route may not provide a reliable estimate of travel time. Muni has established an on-time performance standard that a vehicle arriving three minutes after its scheduled arrival time is considered late[8]. About 70 to 75 percent of the Muni vehicles are on-time according to this criterion.

3.4.2.4 Golden Gate Transit (GGT)

GGT relies upon ride and point checks to monitor its performance.

GGT conducts two types of on-time performance monitoring. The first type covers almost every route and is performed on a quarterly basis. The second type is conducted for specific routes as needed. Point checks are used in the quarterly analysis. The check is conducted at eighteen transfer points during three time periods during the weekday[9] and on weekend days. A total of about 3,100 bus runs are recorded each quarter. About 41 percent of the bus runs observed are during peak hours, another 41 percent are conducted during the midday period, and the remainder (18 percent) are observed on weekends. The number of bus runs observed per route is a function of the frequency of service. The number of observations made at each transfer point is determined by the number of bus routes that pass through it; hence, the number varies significantly. For example, over 1,000 bus runs were observed at the San Rafael Transit Center while about 100 runs were recorded at the Marin Civic Center in the first quarter of 1998.

In addition to the quarterly study, GGT monitors routes on which problems are reported. The monitoring effort could include both ride checks and point checks. On-time performance reports are not generated in this type of monitoring and the information obtained from this process is only for internal use of staff members.

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[8] Because many of Muni’s routes have a headway of six minutes, Muni uses a narrower window to define on time.

[9] Morning peak, midday, and afternoon peak periods.

For quarterly analysis, arrival times are recorded manually on paper and are then entered into a DOS version of Quattro Pro for further analysis. Data recorders designate whether the bus runs are on-time by comparing the scheduled to the observed times. The delay times are not entered into the computer. Data are organized by time points and time periods during which the observations were collected. On-time performance is measured for each time-point checked, each category of time-point, time of day, as well as the entire system of GGT.

The raw datasets provide the number (and percentages) of bus runs that are recorded as early, on-time, or late for each route. Currently the checkers manually record on paper the time the buses arrive.

GGT makes minor revisions to schedules each quarter. Major revisions are made annually. Schedule adherence is monitored and observed travel times are used to adjust the schedules to reflect a more realistic estimate of travel times.

Three standards are used to evaluate on-time performance including one for buses that pass through toll plazas, one for ferry-feeders, and one for other buses. Buses that pass through toll plazas are considered on-time if they are no more than one minute early or less than ten minutes late. Ferry feeders are considered on-time if they are no more than five minutes early or late. Other buses are considered on time if they are no more than one minute early or less than five minutes late. Based on the standards used for ferry feeder service and other buses, GGT achieved 92.5 percent and 91.1 percent on-time performance in the first two quarters of 1998.

Given the on-time performance of GGT, it can be concluded that the published schedule is reasonably reliable for bus routes that do not pass through toll plazas. Therefore, using the schedule alone to estimate transit travel times is an acceptable methodology for GGT routes that do not pass through toll plazas.

For routes that pass through toll plazas, the on-time performance data may not help estimate travel time because the window used (ten minutes) is rather wide. In order to better estimate travel times on these routes, the duration of delay of each bus run can be recorded when point check is conducted.

3.4.2.5 Santa Clara Valley Transportation Authority (VTA)

VTA provides three types of services: local bus, express bus, and light rail. Currently sixty-one local bus routes, twelve express routes, and one light rail route are in operation. VTA currently relies upon ride and point checks to monitor its performance.

Half of the light rail vehicles are monitored every month by point check, requiring two months to complete one cycle of monitoring.

Bus schedule adherence monitoring at VTA involves two types of measuring procedures. Everyday inspectors conduct what is called the “spot check”, a form of point check, at different locations. The check locations are selected either because they are located where delays have been reported by riders or because they have not been checked for a given period of time. Inspectors record bus runs during a selected time period. The spot checks are performed to fulfill the FTA Section 15 requirement including the collection of ridership data.

In addition to this daily monitoring effort, VTA also conducts a more comprehensive ride check for each of the sixty-one bus routes. Approximately thirty routes are checked every year. It takes two years to complete a cycle of ride checks for all of the bus routes. Bus runs are sampled randomly and proportionally service frequency. The number of observations per route ranges from thirty to almost one hundred.

The two on-time performance data collection efforts record about 3,500 to 4,000 observations for the bus system per month. One indicator of on-time observations is derived from the two datasets.

VTA uses a program written in PASCAL language to analyze on-time performance data which are input to the central computer through hand-held computers. These data can be converted into ASCII format, which can then be imported into a variety of Windows applications. Nonetheless, it should be noted that the datasets consist of many variables that are not necessarily related to travel time. Therefore, additional processing of the data should be anticipated, if MTC were to use the raw data directly.

Minor revisions to schedules are made each quarter. Major revisions occur annually.

A bus run is considered late if it arrives five minutes or more after the scheduled time. For light rail, the on-time performance standard used is four minutes. Although on-time performance for each route or for a particular time-of-day is not usually computed, the data are available so the computation is possible.

VTA buses arrive on-time about 90 percent of the time. The performance of light rail is comparable to that of the buses, i.e., 90 to 92 percent of the vehicles run on-time. Given the frequency of monitoring and the reliability of the published schedules, the schedules of bus and light rail would give a reasonable estimate of travel time.

3.4.3 Accuracy

The raw on-time performance data currently collected by transit operators would be the most accurate means for obtaining transit travel times, however; the data is ordinarily only samples of a few of all the routes operated by each agency. Some agencies collect large samples of data frequently, others collect much smaller samples very infrequently. The data is also typically manually recorded and can be difficult to collate and transmit to an outside agency.

Published schedules provide a reasonably accurate estimate of segment-based travel time for most transit operators. Most of the transit operators surveyed update schedules quarterly and most operators are able to achieve 80% to 90% on-time performance within 5 minutes of the scheduled time (see Exhibit 9). However, even when system-wide on-time performance is quite high, certain routes may have much lower rates of on-time performance. If segment travel times are desired on a corridor, rather than regional basis, it may be desirable to adjust schedule travel times based on route-level on-time performance results.

Exhibit 9. Transit Operator On-Time Performance Monitoring

Agency	Regular Monitoring	Additional Monitoring	Window used for Schedule Adherence	Percentage on-Time (system-wide)
BART	Daily	None	5 minutes	90-95%
AC Transit	Quarterly	As needed	5 minutes	80%
Muni	Once every 10 years	Almost daily	2-3 minutes	Not Reported
GGT	Quarterly	Almost daily	10 minutes for buses through toll plazas; 5 minutes for other buses	91-93%
VTA	Once every 2 years	Daily	5 minutes for buses; 4 minutes for light rail	88- 90% for buses; 90-92% for light rail

Source: BART, AC Transit, Muni, GGT, and VTA. October, 1998.

Among the operators interviewed for this project, published schedules are likely to be insufficient proxies for travel time data: Muni and the San Francisco bus routes of Golden Gate Transit. Published schedules are not a reliable indicator of transit travel times for Muni, because of it's limited collection of on-time performance data (collected every ten years) and the rather low on-time performance achieved by this agency. Golden Gate Transit allows a 10 minute delay in its overland routes serving San Francisco, which is a large window of uncertainty when estimating point to point travel times via transit.

3.4.4 Cost Information

The cost of obtaining published schedules is negligible.

The cost of obtaining raw on-time performance data can be quite significant. No cost estimate is provided here but the following tables indicate the availability of dissagregate raw data, the storage format in which it could be made available, and the likely ease of transferring the data.. (See Exhibit 10 and Exhibit 11.) A major complicating and costly factor is the need to use different methods to retrieve and analyze data from each operator.

Exhibit 10. Availability of Dissagregate Transit Time Data

Operator	Level currently reported	Other Level(s) at which on-time performance can be made available
BART	System	Route, time of day, time point
AC Transit	System and selected routes	Time point; time of day
Muni	Not Available	Not Available
GGT	System; time of day; time-point	Route
VTA	Type of services (bus and light rail)	Route, time of day, time point

Source: BART, AC Transit, Muni, GGT, and VTA. October, 1998.

Exhibit 11 Summary of Software Used for Schedule Adherence Analysis

Operator	Software	Ease of File Transfer
BART	TMAP (Windows-based)	Easy
AC Transit	Microsoft Excel	Easy
Muni	RUCUS (DOS-based)	Cumbersome
GGT	Quattro Pro for DOS	Moderately easy
VTA	PASCAL program	Moderately easy

Source: BART, AC Transit, Muni, GGT, and VTA. October, 1998.

3.4.5 Automatic Vehicle Location (AVL)

The use of AVL has potential to improve on-time performance monitoring by the operators as well as provide raw data travel time that could be used directly by MTC. However, the limitations of working with raw data from multiple operators would likely still apply.

Nearly all of the large regional operators and a handful of smaller operators are considering or planing to implement AVL systems. At the current time, only BART, Napa Valley Transit, and Central Contra Costa Transit Authority (CCCTA) have AVL systems that allow real time tracking of transit vehicle location. The systems used by Napa Valley Transit and BART have on-time performance monitoring capabilities. CCCTA is expected to develop this capability in the near future.

- AC Transit has been testing GPS equipment on ten of its buses. They expect full implementation of GPS to be completed by July, 2000.
- VTA is presently reviewing bids submitted by AVL system providers. It is expected that a radio-navigation system will be in place at least two years from now.
- Muni is considering the possibility of installing an AVL system as well. However, no funding has been secured yet. There will be a pilot test, provided by an AVL system provider, on the line 22 in the near future. As far as actual implementation is concerned, there is no concrete plan at this point.
- GGT has also explored the potential deployment of AVL systems. However, it is not likely that such systems will be implemented in the near term.
- SamTrans has tested AVL with schedule adherence capabilities on a small number of buses. At the current time, there are no plans for system-wide deployment.
- Sonoma County Transit has received funding to implement AVL on selected buses and plans to expand the system to its full fleet.

Allowing for the fact the only one car in a train needs to be instrumented, and allowing for the AVL systems already in place on BART and Napa Valley Transit, it appears that about 3,000 transit vehicles would remain in the region to be instrumented with AVL at a cost between $12,000 and $30,000 per vehicle[10].

3.5 Truck Tracking

This section discusses the issues involved in working with truck operators to track truck travel times.

MTC and any other agency, always have the option of using any of the previously discussed vehicle tracking techniques (license plate matching, passive probes, etc.) to track trucks. The only difference would be the need to negotiate with the truck operator for permission to place any transponders or data recorders in the trucks and to arrange for their operation.

This section focuses on the second option where MTC or others seek to obtain from the truck operators the truck travel time information they may already be collecting, or that they might be willing to collect with some additional equipment or survey forms provided by MTC.

3.5.1 Truck Tracking Technologies

Technologies for tracking truck movements include:

- Fleet management technologies;
- Dedicated short-range communication readers;
- Smart cards; and
- Global positioning satellite (GPS) systems.

Fleet and vehicle management systems include onboard computers, routing and dispatching software, mobile communications, and automatic vehicle location (AVL) systems[11] (see Exhibit 12). The data collected by these systems are proprietary and in most cases highly sensitive, but in aggregated form may be made available for public sector planning efforts.

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[10] AVL Systems for Bus Transit: A Synthesis of Transit Practice, TCRP Synthesis 24, Cambridge Systematics, Inc., and Transportation Research Board, National research Council, 1997. The cost per bus figure of $13,700 is based on a survey mailed to 29 transit agencies in the U.S. and Canada. The survey found that the average cost per vehicle for both GPS and signpost systems was about the same. Based on figures provided by survey respondents, the minimum cost for even a small AVL system (32 buses) is about $350,000 or $10,940 per bus.

[11] U.S. Department of Commerce, Bureau of the Census, Truck Inventory and Use Survey for 1987 and 1992. In 1987, the TIUS statistics show that less than 0.01 percent of the nation’s medium and heavy trucks were equipped with trip recorders, electronic engine controls, automatic vehicle identification transponders, or automatic vehicle location systems. In 1992, TIUS statistics show that just under 4.0 percent of trucks were equipped with more than one of these technologies.

Exhibit 12. Fleet and Vehicle Management Systems

System	Applications	Major Users
Electronic Trip Recorders/ Onboard Computers	Automatically monitors and records information on performance of the vehicle or the driver	Large or private fleets; carriers with national or regional operations
Static Routing and Dispatching Software	Computes most direct route between an origin and a destination, enabling carriers to maximize fleet efficiency	Carriers operating on fixed routes with the same customers
Dynamic Routing and Dispatching Software	Uses real-time congestion and shipment volume information to determine the most efficient route for a vehicle	Carriers operating large numbers of vehicles over variable routes; national fleets
Communications Systems	Provides driver-to-driver communication and a link between the carrier's terminal, dispatch office, and vehicles	Large fleets, especially those with time-sensitive cargo and variable routes
Automatic Vehicle Location	Real-time identification of a vehicle's location; package tracking and routing	Truckload carriers operating over long distances

Roadside **dedicated short-range communication** (DSRC) readers, which typically are installed as part of electronic toll collection (ETC) or electronic weigh-station bypass systems, can record the time that transponder-equipped vehicles pass by particular sites. If unique transponder identification codes are used, the comparison of pass-by times for a vehicle that drives by more than one DSRC reader on a single trip can yield estimates of travel times and speeds along certain highway corridors. Comparing these travel times and speeds across multiple trips can yield estimates of travel time reliability. Although the growth of ETC and ITS/CVO programs is swelling the number of trucks equipped with DSRC transponders, planning agencies may equip publicly owned vehicles (e.g., transit buses) with this equipment, or enlist major commercial fleets to serve as "probe" vehicles. Similar data may be obtained from license plate readers (LPR) as they become more widely available.

Smart Cards (an extension of ETC tags to other uses) are integrated circuit cards the size and shape of a credit card, containing an electronic chip that allows them to process and store information. Smart Cards are used as part of gate transactions to identify drivers and motor carriers; or to pay tolls or purchase gas electronically. By comparing Smart Card readings for the same vehicle or driver at two separate locations can help track vehicles and provide information on travel times and speeds, route selection, and O/D patterns.

GPS consists of a global positioning satellite receiver with data recorder located in the truck.

3.5.2 Recruiting Freight Carriers

The pilot study of truck operators (conducted as part of this project)[12] found a great deal of willingness to cooperate on the part of many freight carriers in the Bay Area. However, only the smaller operators were able and willing to respond in the one month time frame of the pilot study. Larger operators, such as Federal Express or UPS, could not or would not participate without more time to obtain management review and approvals.

One key issue for participants was the excessive detail of the survey instrument tested and the demands it placed on the volunteer freight operators. A recommended revised survey instrument is included in the appendices for use in future studies.

The key to future success in recruiting participants will be to work with the California Trucking Association to identify willing participants, and to meet face to face with the participants to work out the details of the data collection effort. This face to face meeting is required to persuade the carrier of the benefits of participating in the survey and to customize the data collection effort to each freight carrier's operation, labor agreements, and record keeping system.

One promising option for recruiting freight operators is to offer the loan of a GPS unit to record their trucks' daily operations. Many smaller operators would like to increase their ability to truck daily track operations and verify the GPS information against less detailed manual logs.

Battelle Corp. recently recruited truck operators throughout California to participate in a California Air Resources Board study of truck operations[13]. The study involved installing GPS tracking and data storage devices in selected trucks and recording a week's worth of data. The devices were professionally installed and then removed at the end of each data collection period. The portable devices could only be installed in trucks with electronic ignition (post 1987 trucks) and tied up the cigarette lighter in the trucks (causing some irritation for drivers that smoked). The only problem was reassuring the truck drivers that the GPS devices were not going to be used as speed enforcement devices so that the drivers would not disconnect the GPS device. However, managers of the participating trucking firms were quite pleased because the new GPS equipment allowed them to track schedule and route compliance by their drivers. Managers found this information of direct value to them and were consequently quite happy to participate in the travel time studies.

An important consideration in recruiting survey participants is obtaining an adequate and representative cross-section of freight operators in the Bay Area. The importance of obtaining an adequate cross-section will depend upon for what purpose the data will be used. For anecdotal use, a representative cross section of carriers may be less critical.

The carriers surveyed should include: For-Hire Truckload Carriers, For-Hire Less-Than-Truckload Carriers, Private Truckload Fleets, Private Distribution Fleets and Service Fleets

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[12] Details of the truck operator pilot study, such as companies contacted and information requested, can be found in the Task 7 report for this project.

[13] Dave Wagner, Battelle Corp., California Truck Activity Studies, California Air Resources Board, Sacramento, CA.

(utility company, public agency vehicles). The recommended percentage representation for each carrier type, as shown in Exhibit 13, is based on the percent each type represents of Bay Area truck volumes[14], plus an estimate of appropriate target samples for private distribution fleets and service fleets.

Exhibit 13. Target Sample Percentages for Freight Carriers

Freight Carrier Type	Target
For-Hire Truckload Carriers	30%
For-Hire Less-Than-Truckload Carriers	5%
Private Truckload Fleets	45%
Private Distribution Fleets	20%
Service Fleets	neg.

neg. = negligible

3.5.3 Data Collection

Driver logs are the most commonly available source of travel time data for freight carriers not equipped with automated fleet management systems. Drivers manually record the location and approximate time of each stop they make. The logs typically include trip start and end times, customer's names, city, and odometer readings. The route taken between stops is not recorded.

Other sources of travel time data that are not as commonly available include electronic toll both receipts, electronic fuel tax reports, dispatch logs.

Carriers are reluctant to release copies of their driver logs, so most of the participants in the pilot study went to the trouble of manually transcribing the driver logs into a survey sheet provided by MTC. This was a significant burden for those small operator/owners who participated in the pilot study.

3.5.4 Accuracy

Driver logs are not typically recorded to the nearest minute. Drivers appear to estimate their arrival and departure times to the nearest 5 minutes.

The precise location (address or cross street) of each stop or customer are not typically recorded in the driver logs, because most companies already know where their customers are located. Companies however will not release customer names and would prefer to go to the effort to manually substitute an approximate cross-street for the customer name in any trip log data they release to the public. Thus the geographic location is usually reported to the nearest cross-street.

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[14] Source: Truck Travel in the San Francisco Bay Area as summarized by MTC from the Truck Travel Inventory and Model developed for the Bay Area, 1993.

3.5.5 Cost Information

The cost to public agencies requesting travel time information from freight carriers consists of the labor involved in identifying and recruiting survey participants, plus data entry and geocoding.

Unlike surveys of the general public, freight carriers must be recruited on an individual basis with more than one month lead times to allow for necessary approvals by management. Phone contact is not sufficient to secure the necessary rapport with participants. Each company must be visited face to face on-site to persuade them of the benefits to them of participating in the survey and to work out the details for each survey of each carrier. This extensive contact effort is necessary to secure the voluntary cooperation of businesses that not familiar with working with non-regulatory public agencies.

Data entry can be expensive and complex because MTC will likely have to accommodate a mix of electronic and manual driver log data in a variety of formats and styles to facilitate the process for the participating companies. Automation is the key to cost effectiveness yet travel diaries are not currently at this level of sophistication. Many data will have to be input manually, yet the range of formats will increase the challenge of properly training data entry personnel. Also, handwriting often is difficult to read and faxed copies impair the legibility of the driver logs even further.

Because drivers do not record addresses, identifying and geocoding origins and destinations will require substantial additional time and expense. Travel diaries have customer numbers, names, and city locations that must be matched with other company information . MTC would have to spend most of the effort geocoding during the first data entry period. In an on-going survey, this geocoding effort initially will require work to match driver logs with more detailed customer information. After the initial geocoding, the subsequent updates and additions to the origins and destinations will not require a substantial effort to the extent that drivers follow a set route. The cost effectiveness of geocoding is increased when using a panel survey because the origin and destination points are greatly reduced compared to a random sample process where these points are not as likely to repeat.

There is also a significant labor cost for companies participating in the survey, but this is not estimated here.

4. TRIP MAKER TRACING TECHNIQUES

Trip maker tracing techniques employ various innovative approaches to survey travelers before or after they have completed their trip. A "prospective" survey recruits volunteers in advance to record and report their travel times as part of their daily activities. A "retrospective" survey asks travelers about their trip after the fact. A prospective survey requires more contacts with the volunteer and delivers more precise information than the retrospective survey, but the prospective survey is a more expensive survey method.

There are already several agencies in the Bay Area that routinely survey travelers. It is possible to include a few travel time questions in these surveys at very little added cost.

4.1 Retrospective Surveys

Retrospective surveys quiz the traveler about their trip after the fact. Most retrospective surveys have focused on the origin/destination, and mode of travel for the trip, rather than the travel time. A couple of pilot tests were made as part of the current project to test the feasibility of using retrospective surveys to obtain commute times.

The traveler is not prepped in advance in a retrospective survey, so questions must be limited to what can be reasonably remembered from the previous day's or that morning's commute. If precise travel times between specified points is all that is desired, a retrospective telephone survey is not likely to be the best mechanism. Various prospective survey methods that contact the traveler in advance would be better. However, if "opinion" type, attitudinal information, or perceived travel times and trip sequences is desired, it is a good option.

Variations on the retrospective survey approach focus on different methods for selecting and contacting trip makers. They include household surveys, employer surveys, and the use of website surveys.

4.1.1 Household Interview Surveys

Household surveys are usually conducted by means of the telephone. Random digit dialing (RDD) is the typical method in telephone surveys to obtain a statistically valid random sample. This method involves using random digits to select the phone numbers to be called from within a target area code and prefix number. Achieving a connection to a person willing to remain on the telephone often requires 20 to 25 calls. To improve the hit rate one might instead purchase a phone list for the desired geographic area or population of travelers, but even with a phone list, only about 1 in 7 numbers are likely to be found at home after a reasonable number of tries, and willing to respond to the survey.

For a corridor specific survey it is best to construct a pre-screened call list for each corridor. These call lists would result from other preliminary data collection methods. For example, to identify travelers in the I-80 corridor video license plate and/or post card methods could be used to acquire a list of potentially willing participants. The "hit" rate using a pre-screened call list, developed by one of these methods, increases generally to 1 in 5. Commute and non-commute trips can be covered and the transit dependent population can be included.

To reach transit users postcards could be distributed at key transit access points including primary corridor related intermodal points, park-n-ride lots, ferry terminals, and BART, commuter rail or light Rail stations. Pedestrian and bicycle users could be accessed by surveying at key funnel points (e.g., trail and bridge entrances) or though interest group outreach.

As part of this project a draft retrospective telephone home interview survey instrument was developed and pilot tested. It is included in the appendices.

4.1.2 Employer Surveys

There are several methods for reaching employees in their workplace and surveying them on their commute patterns. The employer surveys tested were much less expensive than typical home interview surveys because volunteers were used to distribute the surveys and because a smaller number of individual contacts must be made for employer surveys. For example, suppose getting permission to survey employees at one site leads to 100 completed survey; to get an equivalent number of completions with for home surveys, more than 100 contacts would be necessary. The surveys can be conducted on paper, rather than requiring a trained investigator to orally interview each respondent. Employer surveys however exclude, by definition, unemployed people from the sample. More detailed information about the employer surveys field-tested in this project can be found in the Task 7 Report.

Several resource groups maintain lists of public and private employers with contact persons that are willing to participate in an employer survey. The pilot project identified the following major resource groups.

- RIDES for Bay Area Commuters
- BAYCAP (Spare-the-Air Campaign)
- Bay Area Council
- Oakland Network for Employee Transportation (ONET)
- Silicon Valley Manufacturing Group

RIDES can provide several bicycle-oriented lists of commuters to supplement standard employee lists.

Public agencies are a ready source of easily contacted individuals who are already highly trained and predisposed to be highly cooperative with public agency surveys. Technical advisory committees (TAC) for MTC and for the various Congestion Management Agencies provide a ready source of technically qualified and motivated volunteers willing to distribute and collect surveys from their fellow employees.

A pilot test of the retrospective employer survey technique was conducted as part of this project. It found that the demands placed upon volunteers distributing and recovering the paper surveys could be quite light, and that the responses represented an adequate cross section of Bay Area demographics for working people. Members of one MTC and one CMA technical advisory committee (TAC) were recruited to distribute and collect paper survey instruments at their place of work. Additional recruits were found through RIDES and ONET. Eleven recruits came from public agencies, four came from private employers. Fourteen of the 15 recruited contacts successfully performed all of the survey tasks, and most contacts indicated that they would be willing to participate in this type of survey process once or twice a year. A total of 170 completed forms were obtained out of 350 distributed, for a response rate of 48%. It would have been possible to survey about 2400 employees with these 15 recruits if a full survey had been performed, rather than a pilot test.

A comparison of the demographics of the pilot test responses with the region's demographics found the survey respondents to be fairly representative of the region. Employer surveys however will miss unemployed people, especially people under 18 years of age and over 65 years of age.

4.1.3 Website Surveys

This technique consists of distributing an e-mail notification with a HTTP website address embedded within the message. Survey recruits with Internet access can simply "click" on the embedded website address and immediately go to the survey. Also, they can send e-mail directly to MTC if they have any questions regarding the survey or the study.

A pilot test of this method was conducted as part of this project. The website survey was created by the MTC webmaster based on the paper form developed for the separate employer survey pilot test of public agencies. The survey forms differed only by the addition of a question to the website survey to determine how respondents had been directed to the website. As part of the website development, an additional website location was created that "logs" the responses of those participating in the survey. This site is easily accessed by the survey manager via the Internet and then the file can simply be saved to disk. The database developed as part of this pilot test has a macro that automates the importing of this log file once it has been saved to disk.

The website survey was accessed via a "hot link" embedded in an e-mail notification that was distributed to selected e-mail lists of private employers recommended by RIDES, the Silicon Valley Manufacturing Group, and bicycle-oriented groups recommended by RIDES. A total of 75 responses were received on the website out of an estimated 1,200 people who had been notified via e-mail, for a response rate of 6%. The response rate from one of the participating employers, Varian Corporation, whose employees we know did indeed have Internet access, was very good (45%). This indicates that working with employers whose individual employees have e-mail capabilities and access to the Internet could be a very effective means of recruiting employers to provide us information on their commute trips.

Comparing the demographics of the pilot test respondents with ABAG 1990 data for the region identified several potential demographic biases primarily in the use of the website survey method. People identifying themselves as non-white and women were significantly under sampled in the website surveys. The median income of respondents to the website surveys was also significantly higher than for the region. This could be due to the focus of the e-mail notifications on a single large employer located in Silicon Valley, a traditionally higher income area.

4.1.4 Accuracy

Retrospective surveys suffer from the following problems:

- Retrospective surveys are recollections of the previous day, or previous 24-hours of travel activity. Recalled trip times from surveys may differ significantly from actual trip times based on several factors, including traffic conditions and length of a trip. There are always errors in recollection, and the distribution of such errors may not be random (e.g., there is a tendency for short, frequently made trips to be forgotten by respondents; whereas longer, more atypical trips are more often remembered).
- Respondents will inevitably round their response to the nearest 5, 10, or sometimes 15 minute answer. This limits the precision with which data can be used for assessing modes travel time changes (given that most auto trips are in the 10 to 30 minute range, those poses a significant limitation). However, it can be used to establish a baseline (much as the decennial census does) for changes in travel time over a period of years.
- Even when asked about door-to-door travel time, some respondents will give their in-vehicle (line haul) travel time. This can be overcome to a degree by asking additional questions about trip components, such as walking, waiting, transferring, and so on (e.g., how long did it take you to walk from your place of work to your car?).

The use of the telephone to contact trip makers also introduces its own biases:

- The person answering the phone in a household may bias the response to particular household members (in this sense, it is not truly randomized)
- Low income households are often reluctant to answer a telephone survey, may not speak English well, or may not have a phone at all
- The probability of finding a respondent at home is negatively correlated with the number of trips made. An elderly person making few trips is probably fairly easy to reach at home. A traveling sales person on the road most of the day is unlikely to be at home to receive a survey phone call. There has been some discussion of surveying people in car phones, but at present the billing structure would require the respondent to pay for the call. Pacific Bell has proposed a tariff change that would allow the caller to pay for calls made to cell phones, which would improve the response rate for such calls.

The website survey, resulted in significant under representation of women and minorities in the responses. The employer survey using public agency volunteers to survey public agency employees however resulted in few demographic bias problems.

The pilot test of the employer survey found that the mean reported commute travel times for specific origin-destination pairs averaged about 5 to 10 minutes higher than actual commute travel times. This represents an error of between 10% and 20% of the actual door to door travel times. This memory error on the part of the respondents may be due to the natural inclination of respondents to round times to the nearest 5 minutes.

4.1.5 Cost Information

Retrospective telephone surveys typically cost about $40 to $80 per completed household depending upon the length of the survey instrument and the number of calls that have to be placed before obtaining a qualified and willing respondent.

Employer surveys, where the survey instrument is voluntarily distributed and collected by the employer typically cost public agencies on the order of $5 per completed survey to hire a consultant to process the completed forms. Distribution, recovery, and printing costs are negligible or absorbed within the agency's daily operating expenses. The use of a website survey instrument with e-mail notification did reduce this cost to the agency conducting the study to about $3.50 per completed survey. (The primary savings of using a website is being able to skip the data entry step for paper responses.)

4.1.6 Local and National Experience

Retrospective surveys have not in the past been used to collect travel time information because of the imprecise nature of people's recollection of prior day travel activities.

In 1994 Nelson\Nygaard and Dowling Associates completed a retrospective survey for the California Air Resources Board (CARB) to test the effects of travel behavior under various travel time assumptions. This was a general public telephone survey using randomly selected residential phone numbers (listed and unlisted) provided by Survey Sampling, Inc. (SSI). This survey addressed many of the same issues that MTC is interested in pursuing with this survey. The survey asked adults about the trips they took on the day before the call. Detailed information was collected about the point to point elements of the trip, the mode used, perceived travel time and other key elements.

The pilot tests conducted for this project tested the feasibility of using traditional employer surveys and website surveys to gather travel time information from travelers. Details on the surveys can be found in the Task 7 report for this project.

4.2 Prospective Surveys

Prospective surveys involve at least two contacts with each individual; one contact to recruit the individual, a second contact to collect the information after the end of the survey period. A third contact may be required to deliver a trip diary form or a GPS unit to the individual to aid in recording information. Reminder phone calls may also be required.

The advantage of prospective surveys is that travelers can be asked in advance to note a great deal of detail about their trips, including travel times for specific segments of the trip. Prospective surveys are routinely used by public agencies to gather detailed trip behavior information, including travel time.

Variations of the prospective survey technique generally involve the technology used to gather, record, and later retrieve the data. They include:

- Manual recording of trip data in a paper trip log,
- The use of global positioning satellite (GPS) receivers and data recorders to automatically track the volunteer,
- E-mail reporting of the day's trip making, and
- Cell phone call-in during the trip.

4.2.1 Manual Trip Log Method

Volunteers are asked to track their travel by using a trip diary or other trip logging device (such as a portable GPS receiver and recorder) that is provided to them. The trip diary is then retrieved from the volunteer either by a call back telephone survey, a messenger service, or by postage paid return envelopes.

The MTC household travel survey, conducted in 1990, is an example of a prospective survey approach. The survey requested that residents maintain a daily travel diary for a week. The data was retrieved at the end of the week by telephone. A total of 10,800 successful household surveys were completed at a cost of approximately $100-$150 per completed household.

A panel may be used to improve tracking of changes in travel behavior over time. The panel is a small group of respondents that agree to be contacted several times over several years. The advantage of using a panel is that the panel becomes experienced with the survey and much more detail can be obtained. The difficulty is that panels shrink in size over time as people move or tire of participating.

4.2.2 GPS Receiver With PDA Recorder

The Lexington, Kentucky MPO tested a novel volunteer technique that involved the use portable GPS equipment. Volunteers were contacted and recruited by telephone survey. A portable GPS receiver and trip logging device was then delivered by private courier to the volunteer's house along with both written and video-taped installation instructions plus a check for $25.00. Installation required the volunteer to plug the device into their car's cigarette lighter, mount the receiver antenna on the roof, extend the antenna cable through a window to the GPS receiver sitting on the front passenger seat, and learn how to operate the personal digital assistant (PDA) for logging trip purpose and other traveler data. A week later a delivery service was sent to the house to pick up the equipment and deliver another check for $25.00 along with a "thank you" letter. The data was then downloaded and processed back at the office.

An estimated 30% of the GPS trip data was lost due to poor installations, battery failures, and loss of satellite signals. Most of the data loss problems were related to failure of the GPS receiver to obtain adequate satellite signals. However, the remaining GPS data did show a significant number of otherwise unreported trips being made. The study included a traditional day after telephone survey so that the GPS trip logs could be compared to traditional trip survey results.

4.2.3 E-Mail Reporting

E-mail reporting is an alternate method to obtaining trip logs once the surveys are completed. Volunteers record their travel patterns for the day, and then at the end of the day fill out a standard form on their personal computer which they then e-mail to the survey agency. This approach saves the expense and delays of contacting volunteers by phone to record the data, or waiting for the volunteers to mail back their trip logs.

4.2.4 Cell Phone Call In

Cellular phone reporting is an innovative approach that has been tested in Houston and is used by SmartRoutes, a private travel information service in Boston, Cincinnati, Philadelphia, and Washington, D.C. Volunteers with cellular phones in their vehicle call in to a central number at various check points during their commute trip. The travel time between checkpoints is recorded and the information reported to subscribers to the service.

Private news radio stations in the Bay Area, in cooperation with local cell phone service providers (GTE/KCBS, and Cellular One/KGO) provide special toll free cell phone numbers (such as *KCBS) that cell phone subscribers can dial to report incidents on the road. Callers are then given the gratification of hearing their first names reported on the air. The Bay Area systems have not to date been used to report numerical data, such as travel times between check points.

4.2.5 Local and National Experience

Prospective surveys of travel behavior have been used for decades by most every large metropolitan planning organization in the country. GPS and cell phone reporting have only just begun to be tested in the last few years.

- MTC has used the prospective survey method with manual recording of trip logs in its 1980 and 1990 travel surveys.
- FHWA experimented with providing portable GPS units to volunteers as described above for Lexington, Kentucky.
- Texas DOT is experimenting with GPS receivers as part of a household survey in Austin.
- Cellular phone reporting was tested with minor problems in Houston in 1993 prior to implementation of the AVI probe vehicle system.
- Cellular phone reporting is also used by SmartRoutes, a traveler information provider, in Boston, Cincinnati, Philadelphia, and Washington, D.C., with scheduled launches in New York and Minneapolis.

4.3 Utilizing Other Survey Efforts

Ongoing traveler survey efforts by public agencies in the Bay Area currently obtain completed returns for about 19,000 workers and 2,000 households in the Bay Area once every two years (see Exhibit 14). These surveys generally do not ask travel time questions, but a few travel time questions could be added to these ongoing survey efforts at negligible cost. In addition, MTC routinely surveys about 10,800 households once every ten years.

As described in an earlier section, MTC conducted a household travel survey in 1990, and usually conducts such a survey once every ten years. There were a total of 10,800 successful household surveys in the last survey. As mentioned earlier, the cost of this survey runs between $100 and $150 per completion.

A second but separate survey was done by MTC in 1996, of 2,700 households in the San Francisco Bay Bridge corridor for the Congestion Pricing Study. These special studies are not routinely scheduled, but are made in response to specific project needs.

The other public agencies generally conduct retrospective surveys at much lower costs. They take care of distributing the survey forms themselves and hire a consultant just to process the results. Many of these agencies base their survey questions on the original BAAQMD (Bay Area Air Quality Maintenance District) survey, with modifications to meet the needs of the specific agencies. Survey instruments vary from short (4 or 5 questions) to fairly long (three pages of questions). Only two of the survey instruments currently include a question related to travel time, although most of the surveys include a travel distance question. The typical processing cost per completed survey is about $4.50, although Pleasanton was able to process their surveys for a cost of $1.50 per completed survey.

Most all of the public agencies contacted indicated their willingness to accommodate an additional travel time question or two as long as it did not significantly increase the length of their survey instrument. The sharing of mailing lists is also possible, but that topic has not been broached with the agencies.

Exhibit 14. Ongoing Traveler Survey Efforts in Bay Area

Agency	Frequency	Distribution	Returns	Cost	Contact
Menlo Park	Biennially	25,000 employees	4,500	$20,000	Deborah Helming 650-858-3363
Pleasanton	Biennially	51,000 employees	6,400	$10,000	Diana Bonanno 925-484-8289
San Ramon	Biennially	23,000 employees	3,900	?	Lisa Sanchez 925-275-2296
Multi-City TSM Agency (San Mateo)	Biennially	11,000 employees of large employers	2,300	$10,800	Angela Rae, 650-994-7924
West Contra Costa (WCCTAC)	Annually	15,400 employees	5,500	$5,500	Summer Brenner 510-215-3008
Santa Clara Valley (VTA)	Biannually	n/a	1,000 households	?	Chris Augerstein 408-321-7093
RIDES	Annually	n/a	1,600 households	?	Steve Beroldo 415-281-4304
MTC	Decennially	n/a	10,800 households	$1.0-1.6 million	Charles Purvis MTC

n/a = not applicable.

4.4 Accuracy

Prospective surveys are thought to be more accurate than retrospective surveys because the trip maker records the trip information at the time the trip is made. Comparisons between manual trip logs with GPS logs (done as part of the Lexington Kentucky Study) however pointed out several failings when trip makers must manually record trip data. Travel time rounding and missed stops (short stops on a longer trip that were not recorded) were the two biggest sources of discrepancies. There were also some flat out disagreements between the manually recorded location and the GPS recorded location for some trips.

4.5 Cost Information

Prospective surveys are more expensive than retrospective surveys because they require more contacts and the transmittal of logs or equipment back and forth between the trip maker and the public agency. Costs vary a great deal depending on the complexity of the survey instrument but can run between $100 and $150 per completed household.

Retrospective surveys households are much less expensive, running between $40 and $80 per completion. Employer surveys can be performed for only $5 per completion. A website survey can reduce the cost to $3.50 per completion.

5. EVALUATION OF METHODS

As stated in the introductory chapter of this report, the primary purpose of the Travel Time Pilot Project is to help MTC and the Partnership decide whether and how to pursue system-wide monitoring of historic travel time and variability of travel time. Interest in these measures evolved out of work, completed for MTC by David Jones in 1995, that identified travel time and variability of travel time as important customer-oriented performance measures. MTC hypothesized that this data could be published in a periodic "state of the system report" to facilitate better understanding of customer experiences and to track changes in the performance of the Metropolitan Transportation System (MTS) over time.

In fact, travel time and related data have a number of possible system monitoring applications, only some of which are directly applicable to a state of the system report of the type MTC envisioned. (See Section 5.1.2 for details.) While each application has specific requirements for type of data, accuracy, and coverage, some methods may generate data suitable for more than one purpose. As the study progressed, the importance of these "economies of scope" became more apparent. For this reason, this chapter begins in Section 5.1 by outlining a number of potential data applications and hypothetical specifications for a state of the system report. Section 5.2 identifies the evaluation criteria used. Finally, in sections 5.3 through 5.10 the chapter uses the criteria to asses the strengths and weaknesses of each of the travel time data collection techniques and technological variations explored in the previous chapters.

5.1 Applications of Travel Time Data to Performance Monitoring

5.1.1 Five Potential Applications

We have identified five system monitoring applications that could potentially use travel time data, variability data, and/or the related measures of speed and delay. Three applications involve historic data while two involve real-time data.

Historic Data – The first two applications directly support the state of the system report and are the basis for most of the evaluation criteria applied in this study:

1. Public Information on Customer Perception (or Customer Satisfaction) – David Jones' vision for using door-to-door travel time as a customer-oriented performance measure extrapolates most readily to this application. Data gathered for this purpose would be used by analysts, public officials, and the press to better understand customers' experiences and perceptions of travel time and variability by travel market and mode. Because we are interested in customer perception, we can accept discrepancies between perceived and actual data. The data need not be collected more often than once a year, and the sample need not be statistically rigorous, as the primary purpose is illustrative.

2. Deficiency Identification– Data gathered to identify deficiencies requiring further investigation would be used by agency staff to track MTS performance over time, flag potential problem areas, and prioritize planning efforts. Data must be accurate enough to identify emerging problem areas and understand their magnitude. Therefore it is important to collect a fairly representative sample for any given segment of the system. Highest monitoring priority would be given to those segments on which performance is likely to cross a threshold, for example transit routes or roadways operating near to capacity. Since

this can be difficult to gauge, it would be important to monitor nearly all system segments with some regularity.

The Congestion Management Program (CMP) employs level of service (LOS) monitoring to identify deficiencies. State lay makes each county responsible for designating a CMP network that includes, at a minimum, state highways and principal arterials, and monitoring its performance at least every two years. Counties and Caltrans currently collect travel time and related data (speed and delay) to monitor CMP LOS standards; some counties collect this data for other roadways and for their transit systems but, at a minimum, all collect data for their designated CMP networks. In addition to the LOS monitoring element, each CMP must include a performance element that establishes measures for evaluating the multi-modal system for moving people and goods. Some counties have begun to use travel time between selected O-D pairs to support this multi-modal monitoring element.

Because LOS is not generally recognized as a customer-oriented performance measure, travel time could be used as a supplemental customer-oriented measure applicable at the regional level.

3. Guiding Investment Decisions – Data collected for this purpose could be used by agency staff and decision makers to help prioritize projects for programming. It would be important to collect a representative and accurate sample and achieve even geographic and modal coverage. Data would have to be collected once per programming cycle. MTC has expressed no commitment to using historic travel time for this application.

Real-time Data – Two uses of travel time and related data are being considered in greater depth in a project to develop a data coverage plan for TravInfo, the region's real-time traveler information system. MTC expects to complete this study by summer 1999. The Travel Time Pilot Project did not attempt to understand fully data needs, including data type, or potential collection methods for these purposes. However, this report offers some tentative thoughts:

4. Real-time System Operations – Data gathered for this purpose would be used by technical staff in the Caltrans Traffic Operations Center, other traffic management centers, and transit operations centers to identify and respond to system "failures", such as heavy congestion and/or incidents, in real-time. Data type, accuracy and geographic coverage needs may vary based on the type of response required, e.g. emergency assistance versus congestion management. At a minimum, real-time monitoring must identify the specific facility, segment, and cause of delay.

5. Real-time Traveler Information – Data gathered for this purpose would be transmitted to TravInfo and then to data disseminators for use by the traveling public. The TravInfo study will explore data type, accuracy and modal and geographic coverage needs for this purpose.

In both cases, real-time data must be collected and disseminated in a matter of minutes. Continuous twenty-four hour monitoring is desirable but coverage during the peak hours is most important.

5.1.2 State of the System Report

This study focuses on system monitoring for public information and deficiency identification, applications (1) and (2) above, and assumes the likely product would be a periodic state of the system report. The report, produced perhaps annually, could be used to illustrate customer experiences and track changes in performance of the Metropolitan Transportation System (MTS), the region's primary transportation system, over time. The report should cover a broad range of modes for the commute and non-work markets while keeping costs reasonable. Modes of interest include transit, SOV, HOV, bicycle, and freight.

Exhibit 15. Possible MTS System Report*

		Primary Mode of Travel				
Travel Market	Measure	Transit	SOV	HOV	Bicycle	All
Commuter	Mean Trip Time (min.)	X	X	X	X	X
	10%/90% Trip Time (min.)	X/X	X/X	X/X		X/X
	Mean Trip Speed (mph)	X	X	X	X	X
	Mean Delay/Trip (min)	X	X	X		X
Non-Work	Mean Trip Time (min.)	X	X	X	X	X
	90^{th}/ 10^{th} percentile Trip Time (min.)	X/X	X/X	X/X		X/X
	Mean Trip Speed (mph)	X	X	X	X	X
	Mean Delay/Trip (min)	X	X	X		X
All	Mean Trip Time (min.)	X	X	X	X	X
	10%/90% Trip Time (min.)	X/X	X/X	X/X		X/X
	Mean Trip Speed (mph)	X	X	X	X	X
	Mean Delay/Trip (min)	X	X	X		X

* Could be reported at the segment or O-D level or aggregated to corridor, county or regional level.

Though MTC has not yet developed specifications for an annual state of the system report, we have developed some hypothetical specifications to help focus the evaluation criteria. These specifications should not necessarily be considered qualifying criteria, as the evaluation may show it is too expensive or simply not feasible to obtain some data. However, the criteria can help assess a reasonable level of effort and expenditure. Exhibit 15 illustrates potential mobility performance measures and a possible reporting structure for a state of the system report. Hypothetical specifications include:

- Door-to-door travel times and perceived variability for representative origin-destination pairs and modes – for example, Vallejo to San Francisco via auto, ferry, and train – to illustrate customer experiences and trends for policy makers and the general public.
- Various travel time, speed, delay, and variability statistics by mode for individual corridors and/or system segments – to more carefully track performance or identify potential deficiencies. Delay would be defined as the difference between the actual travel time and a target, such as free-flow or off-peak travel time, identified by MTC.
- Variability of trip times by time of day might be measured in terms of the 90 percentile and 10 percentile travel times. For example, only 10% of the observed trips are longer than the 90 percentile time. The range between the 90 and 10 percentile times shows the kind of variation that travelers can expect.
- Summary statistics at the corridor, county or regional level – to provide a broad picture. These might include statistics based on data other than travel time: for travel by auto, number of miles congested, number of hours per day congested, and percent of VMT (vehicle miles traveled) and percent of lane miles congested; for travel by transit, percent on-time performance.

The following examples show that some measures may be meaningless or difficult to apply for some modes and data collection methods: variability is not a meaningful measure for bicycle travel; transit schedules would not generate data on variability of transit travel times; and freight might be well handled by tracking freight-oriented origin-destination pairs rather than region-wide summary statistics requiring comprehensive (and difficult to obtain) data.

5.2 Evaluation Criteria

The evaluation criteria were developed early in the project to focus on the collection of data for public information on customer perception and deficiency identification, the applications most directly supportive of the state of the system report described above. The following evaluation criteria were used:

1. Coverage (Modal, Temporal/Market, Geographic),
2. Cost,
3. Local experience and coordination with local agency efforts,

4. Length of time needed to implement, and
5. Sufficiency of data for various applications as defined in the previous section, and including data accuracy, and the ability to collect door-to-door travel time and variability data.

Each of these criteria is explained below.

5.2.1 Coverage

The coverage criterion looks at the modal, temporal/market, and geographic, coverage provided by the travel time measurement technique. Ideally, a state of the system report would have broad coverage in all three areas. However, broad coverage may be more important for other applications; for example real-time system operations requires 24 hour coverage.

Coverage of modes measures the ability of each technique to collect travel time data for the following modes: Transit, Arterial, Freeway, HOV, Freight, Bike. The technique and its technological variations are evaluated both for their "inclusiveness" (are any modes not measurable by the technology?) and their ability to distinguish or discriminate between modes.

Temporal and market coverage are essentially substitutes for one another. Temporal coverage refers to the ease with which peak hour, daily, and weekend data can be obtained using the technique. Coverage of markets measures the ability of each technique to collect travel time data for commute and non-work markets. Market coverage is more applicable to the evaluation of survey methods and to the public information application, the first discussed in Section 5.1 above. Temporal coverage is generally more relevant for evaluating non-survey methods and tends to correspond with the other potential applications.

Geographic coverage refers to the effort required to obtain speed and travel time data for the entire MTS system.

5.2.2 Cost

Cost estimates include the cost of collecting, processing, storing, managing and transferring travel time data for each of the methods. To establish a common base for comparison, data collection costs were estimated for full MTS coverage, for example by deploying data collection equipment at regular intervals over the entire arterial and freeway network or the region's entire transit fleet. For nearly any method, one could reduce capital, maintenance and data handling costs by identifying selected MTS roadways and transit routes for monitoring. We assume that the methods are similarly scaleable, except where noted.

5.2.3 Local Experience/Acceptability & Coordination Potential

Local experience, acceptability, and coordination potential includes the extent to which local and state agencies are already using or familiar with the technique. This criterion attempts to assess the potential to coordinate data collection efforts with ongoing data collection activities of the CMA's and Caltrans.

5.2.4 Implementation Time

This criterion relates to the likely amount of time it would take to implement the data collection technique. Short term is considered to be under two years. Long term is any technique likely to require several years to implement.

5.2.5 Sufficiency

Sufficiency relates to the type of data provided and its relevance to the five potential applications discussed in Section 5.1. Because this study did not attempt to assess fully the data needs for the real-time applications, sufficiency for these applications is assessed at a very general level. Likewise, as MTC has no commitment to using travel time data to prioritize projects for programming, the analysis is less through with respect to this application than to customer perception monitoring and deficiency identification. The evaluation addresses the following aspects of sufficiency:

- Data type – Does the technique provide door to door travel time, as is desired for customer perception monitoring? Does it provide segment travel time, as is more valuable for facility monitoring typical of deficiency identification monitoring? Can the variability of travel times be determined from the data provided by each technique?
- Timeliness relates to the rapidity with which the data can be obtained and tranmitted. This is critical primarily for real time monitoring.
- Accuracy relates to the quality of the data provided. Is it sufficiently accurate and reliable for the various applications? Though a state of the system report does not require an extremely high level of accuracy, the more accurate the data, the more likely the data can be used for other monitoring or planning applications.

5.3 Roadside Detectors

Roadside measurement of vehicle speeds is an established technology for collecting speed data. Dual loop detectors are the best available technology for measuring spot speeds. Overhead video detection shows great promise of overcoming the problems that pavement maintenance causes loop detectors; however, image processing software for measuring speeds is still in research and development.

Current real time monitoring efforts use a number of roadside detectors to collect speed and congestion information. These include a system of loop detectors and CCTV cameras. A system of remote traffic microwave sensors (RTMS) is scheduled to come on line in the spring of 1999. The data is supplemented by reports by the California Highway Patrol (CHP) and automated vehicle location data from Freeway Service Patrol (FSP) tow trucks.

5.3.1 Coverage

Roadside detectors provide speed data for all vehicular modes crossing a particular point of the road. Loop detectors are typically not sized to detect bicycles but can be designed to do so where significant bicycle volumes are expected. (Retrofitting existing loops to detect bicycles would be quite expensive.) Video and radar detectors can detect all vehicle modes and can easily measure bicycle speeds, if desired. With some specialized programming it would be possible to distinguish between transit or truck vehicles and general automobile traffic, though it may be difficult to distinguish between buses and trucks unless video detection is used. HOV's not using a dedicated HOV lane would be difficult if not impossible to isolate from SOV's in mixed flow lanes. Technically, roadside detectors can be used on arterials and for transit; however, spot speeds are particularly poor indicators of average speed or travel time when there are significant delays between detectors, such as at bus stops or traffic signals.

Roadside detectors can achieve broad temporal and geographic coverage for measures of spot speeds. Though roadside detectors cannot distinguish various travel markets, permanent roadside detectors, like loops, are ideal for gathering 24-hour and weekend data; they provide 100% temporal coverage, as long they are well maintained. Geographic coverage is restricted only by cost. Indeed Caltrans has plans to install loop detectors throughout the urbanized sections of the region's freeway system, though the actual implementation time line is uncertain.

5.3.2 Cost

Permanent roadside detectors are too expensive to consider for monitoring the entire MTS system unless they are also already in place for other purposes such as ramp metering or signal coordination. The current cost for a roadside detector station is about $12,000 including a wireless modem for communication. Even where the roadside detectors are already in place for ramp metering or signal coordination, there is the significant cost (on the order of $2,000 per station) of then providing communications capabilities for each detector station.

It would require a capital cost of about $4,000,000 to finish installing loop detectors at four mile spacing with vehicle signature matching capabilities for the MTS freeway system alone (No estimate has been made for instrumenting the arterial system of MTS. The existing signal detectors on arterials could be used, but they are not likely to be very accurate.).

Maintenance costs are another significant cost item. It is not unusual to have 10% to 20% of the loop detectors down at any one time because of construction, pavement problems, or other conditions. Experience to date in the Bay Area shows that as few as 30% of loop detectors are functioning at any one time. Maintenance costs on the additional loop detector stations for the freeways are estimated run at least $50,000 per year (possibly much more) assuming an average life between breakdowns of 4 years.

5.3.3 Local Experience/Acceptability & Coordination Potential

There is extensive local and national experience with loop detectors. Single loop detectors are pervasive throughout Bay Area. Dual loop detectors have only recently begun to be installed as the need for speed measurement in addition to traditional counts has become apparent to agencies. Though there is no local experience extrapolating travel times from spot speed data, this is done in other regions. Vehicle signature matching is currently under research.

Video detection is less well known and established and is currently the subject of a great deal of experimentation. Research is currently focusing on the development of the necessary image processing software.

5.3.4 Implementation Time

While the loop technology is well developed, the system of functional loops that collect reliable data remains very small in the Bay Area. The implementation time for using methods depending on the sensors would depend heavily on the commitment by Caltrans of adequate resources to connect and maintain existing loops as well as deploy additional, planned detector stations. Video detection is a few years off, while research continues on image processing software. Vehicle signature matching is also probably also a few years off.

5.3.5 Sufficiency

Roadside detectors do not provide travel time information. They do provide spot speed information. Loop and radar detectors typically provide spot speed measurements that are reliable for maybe the 200 feet in the immediate vicinity of the loops. At a density of 3 detectors per mile, the detectors are actually measuring speed for only 600 feet out 5,280 feet of the facility, about 11% of the facility length. Double loop detectors are quite accurate at measuring speed while single loop detectors are much less accurate.

Depending on the desired level of accuracy, a system double loops and other roadside detectors may provide data sufficient to extrapolate freeway segment travel time from spot speeds. Vehicle signature matching, currently under research, would measure travel times between detector stations and thus could significantly improve the accuracy possible with roadside detectors. Roadside detectors are not reliable for measuring arterial speeds because of the great variation in vehicle speeds depending on the distance the detector is located upstream or downstream from a signal.

Because large amounts of speed data can be quickly gathered and quickly communicated to a central office, roadside sensors are ideal for real-time data applications that rely on speed data. Once the initial high installation costs are overcome they can provide 24 hour coverage at very little additional cost. Maintenance costs though are a major concern for in-pavement loop detectors.

Because roadside detectors provide spot speeds not travel times, they are not considered promising candidates for customer satisfaction monitoring which requires door to door travel times.

Roadside sensors could be used for deficiency monitoring or project programming, but these two uses by themselves would not be sufficient to warrant the high cost of installation.

5.4 Aerial Photography

Aerial photography is an established technology that has only recently been applied to the problem of speed measurement over large geographic areas. The labor necessary to process the photos and the lighting/weather requirements of aerial photography are the two main draw backs to more extensive use of this technology for measurement of speed and travel time.

5.4.1 Coverage

Aerial photography provides speed data for all vehicular modes present in the general area of the photos at the particular moment when the photos are shot. The comprehensive geographic coverage allows the spot speeds to be combined into estimates of segment travel times. Motorcycles and bicycles are difficult to detect unless especially large scale photos are used. Transit and truck vehicles are easily detectable, even when mixed in with general automobile traffic. HOV's are not detectable unless they are using a dedicated HOV lane (the assumption then would be that violators are negligible).

Aerial photography provides very extensive geographic coverage, but very poor temporal coverage, which is limited by the cost of repeating flights multiple times during the day and on weekends. Aerial photography cannot distinguish the trip purposes of travelers and thus cannot determine separate speeds for travel markets.

5.4.2 Cost

Aerial photography can be cost effective for annual monitoring of large systems. It would require an initial capital investment of about $50,000 for a high quality digital camera and data processing software to survey the MTS system. Another $300,000 would have to be spent annually on plane/pilot rental, and data reduction to survey the complete arterial and freeway MTS once each year.

5.4.3 Local Experience/Acceptability & Coordination Potential

Santa Clara County has built up two years of experience with the use of aerial photography for speed measurement. No other local or state agency in the Bay area has used it.

5.4.4 Implementation Time

Aerial photography using densities could be implemented immediately. Time lapse photography will require another year or two of image processing software development and reductions in the cost of high quality digital cameras.

5.4.5 Sufficiency

Aerial photography does not provide door to door travel time information. Large amounts of vehicle speed data for road segments can be quickly gathered; however, the data cannot be processed until the plane returns to the air field and the film is processed and the vehicle speeds manually tallied. Speed variability data is easily gathered for those short periods when the plane is in the air. Density measurements are not very accurate predictors of speed, but time lapse photography can provide quite accurate vehicle speed measurements.

Aerial observation (without photography) is an inexpensive means for obtaining real time information on road congestion. It is currently used by commercial radio for traveler information purposes. This method is excellent for traffic operations monitoring and traveler information. Its one weakness is the necessity for good flying weather. Fog can ground the planes.

Aerial photography is an excellent method for monitoring deficiencies, a large area can be rapidly covered, relatively inexpensively.

The method is not well suited for customer satisfaction monitoring since it does not measure door to door travel time.

5.5 Test Vehicle

Test vehicles (floating cars) is a well established technology for measuring travel times and speeds. The search for alternatives results from the method's limited potential for real-time data collection and its relatively high labor costs.

5.5.1 Coverage

Test vehicle technology provides median speed data representative of all automobiles present in the traffic stream at the time the test vehicle is present on that segment of the facility. It is not an ideal technology for measuring HOV, truck, transit, motorcycle, or bicycle speeds, since, in order to obtain speeds for those modes, the test vehicle must follow individual vehicles for each of these modes. Following individual vehicles increases by five fold the number of test vehicle runs required to obtain a sufficient sample for estimating median speed.

Test vehicles cannot distinguish the trip purposes of travelers and thus cannot determine separate speeds for various travel markets.

Test vehicles can provide relatively good geographic and temporal coverage, but their expense and limited vehicle availability usually limits the number of different routes and facilities that can be measured at any one time.

5.5.2 Cost

It would require an initial capital investment of about $50,000 to instrument 9 test vehicles with GPS. This is the minimum number of vehicles required to survey the entire 6,060 directional miles of the MTS in one year, assuming they operate only on Tuesdays, Wednesdays, and Thursdays, avoid holidays, and obtain 6 samples for each of 6 hours each day. Another $400,000 would be required each year for auto operating costs, drivers, and data processing.

5.5.3 Local Experience/Acceptability & Coordination Potential

Most CMA's and local jurisdictions in the Bay Area use or have used the test vehicle technique (either manual, DMI, or GPS) to monitor CMP program compliance or for signal coordination studies. Caltrans has used the technique for years in its Congestion Monitoring Program, that collected speed and travel time data for the state highway system. DMI has been used by Caltrans and Santa Clara VTA for several years. GPS is a relatively recent innovation that has seen some use locally by the private sector, and some use nationally by public agencies.

5.5.4 Implementation Time

The test vehicle technique with GPS or DMI could be implemented immediately.

5.5.5 Sufficiency

Test vehicles directly provide travel time information between specific points of the system. Median vehicle speeds for specific segments or road can be readily obtained. The variance in speeds is not easily obtained using this technique (sample sizes are usually too small). Door to door travel times are quite expensive to obtain, but they are obtainable using this technique. The median speeds and travel time obtained by test vehicles are usually accurate and reliable, though sample sizes (number of runs) may be limited due to costs. DMI and GPS can improve the reliability of the results by eliminating human error in recording elapsed travel times.

Floating cars are a well established technology but with relatively high labor costs. Consequently, the method is good for occasional survey efforts for project programming and deficiency monitoring. It can be used to perform some limited measurements for customer satisfaction monitoring, but is too expensive (compared to other household or employee survey approaches) to use extensively for this purpose. Real time reporting is feasible with the use of a cell phone; however it is relatively untried and would be prohibitively expensive to cover a large system day to day and for long periods of time.

5.6 Vehicle Tracking - License Plate

License plate matching, a technological variation of the vehicle tracking technique is a well established technology for determining through traffic volumes. It has not been often used for measuring travel times and speeds.

5.6.1 Coverage

License plate matching provides point to point travel time data representative of all through vehicles present in the traffic stream at each checkpoint of the facility. Separate speeds and travel times can be identified for trucks, transit, and motorcycles. Bicycles would be difficult since most do not have license plates. HOV speeds can be easily determined only when they are using an exclusive HOV lane.

License plate matching can provide relatively good geographic and temporal coverage, but its expense usually limits the number of checkpoints that can be measured at any one time. This technique cannot distinguish the trip purposes of travelers and thus cannot determine separate speeds for various travel markets.

5.6.2 Cost

Manual license plate matching would be too cost prohibitive for use in monitoring the MTS system. Assuming video recording stations were permanently installed at four mile spacing over the entire MTS system, the capital investment, including OCR reading and matching software, would be on the order of $15,000,000. Annual maintenance costs would run about $300,000 per year assuming an average life between breakdowns of 5 years for each station. If the method were not used for real-time data collection, the recording stations could be moved so that many fewer would be needed to historic collect data on the full MTS in a given year. This could substantially reduce the capital cost; though the reduction would be offset somewhat by an increase in the set-up costs.

5.6.3 Local Experience/Acceptability & Coordination Potential

Most local agencies in the Bay Area are familiar with manual license plate matching. Few have used video cameras. Specialists with the necessary high speed video camera and playback equipment are relatively rare. MTC did use video for its Altamount Pass study.

5.6.5 Implementation Time

Vehicle tracking using the license plate matching technique would require a few years to install the necessary cameras, develop and field test the OCR software, and develop the plate matching/reporting programs.

5.6.5 Sufficiency

License plate matching can directly provide travel time information between specific points of the system for relatively large numbers of vehicles. The variance in speeds is easily obtained using this technique. Door to door travel times are infeasible to obtain using this technique. The speeds and travel time obtained are usually accurate and reliable although it is difficult to determine if a vehicle made a stop between checkpoints or was merely delayed by traffic.

At the current time, license plate matching is too labor intensive for most any system monitoring use. Future improvements in optical character recognition software may one day make it possible to highly automate the data collection and data processing effort thereby decreasing costs. Such improvements may also make this method well suited for real-time applications.

5.7 Vehicle Tracking - Passive Probe

Vehicle tracking with instrumented passive probe vehicles is a relatively new technology for measuring vehicle travel times and speeds. Variations with potential include anonymous roadside tracking by reading electronic toll collection (ETC) tags and areawide GPS tracking.

5.7.1 Coverage

Passive probe tracking provides point to point travel time data representative of the instrumented vehicles in the traffic stream at each checkpoint of the facility. The method works best when there is a sufficient number of instrumented vehicles. Experience in New York and Texas suggests that obtaining sufficient numbers of ETC probe vehicles should not be a great problem; the tags are inexpensive and small, and it thus is possible to distribute them widely to increase the population.

Separate speeds and travel times can be identified for trucks, transit, and motorcycles if they are suitably equipped with identifying tags. Current plans for deployment of ETC tags in the Bay Area do not provide for anonymous vehicle-type identifiers. Although the tags appear to have the technical capability, introducing vehicle-type identifiers would be non-trivial. It could complicate tag distribution and, since the tags are transferable among vehicles, would involve some level of error. Though bicycles typically would not be instrumented, free ETC tags could be distributed with some kind of incentive.

Though HOV's, such as vanpool vehicles, could be equipped with a special identifying tag, it would not be possible to determine if there were actually two or more people in the vehicle at the time it passes a checkpoint. Vehicles using an HOV lane could be identified by special ETC readers. Some special field calibration of the precise latitude and longitude of the HOV lanes might also allow GPS units to identify when a vehicle is using an HOV lane.

This technique can provide relatively good geographic and temporal coverage, but the installation expense for readers usually limits the number of checkpoints that can be measured at any one time. This technique cannot distinguish the trip purposes of travelers and thus cannot determine separate speeds various travel markets.

5.7.2 Cost

ETC tags have a negligible cost, under $20 per tag, but ETC readers might cost about $10,000 per installation plus telemetry. It would require a capital investment of about $9,000,000 to install ETC reader stations every four miles in each direction on the 3,030 mile MTS system. The annual maintenance cost for ETC readers might run about $300,000 for the 1,515 stations, assuming a 6 year life between breakdowns. GPS units, on the other hand, currently have a very high cost per receiver unit, between $500 and $5,000 to fully instrument each vehicle.

5.7.3 Local Experience/Acceptability & Coordination Potential

There is no local experience with passive probes using ETC tags, but ETC has been demonstrated in several large urban areas of the United States. GPS receivers and on-board computers were recently used by the California Air Resources Board to collect extensive data on truck operations.

5.7.4 Implementation Time

Implementing ETC vehicle tracking would require a few years to establish ETC on the region's bridges, install detectors on the MTS system, and allow ETC tags to percolate through the vehicle fleet. Difficulties integrating software and hardware to date have delayed the installation of ETC on the region's bridges.

A GPS receiver system would take much longer, requiring several years to acquire the necessary equipment, acquire or develop the software, recruit drivers, and to test and develop a communication system for retrieving the stored data.

5.7.5 Sufficiency

Passive probes can directly provide travel time information between specific points of the system for a sample of instrumented vehicles. Generating an adequate sample size (proportion of the entire vehicle fleet) remains the critical factor in achieving a high level of accuracy in speed and travel time and in collecting good data on variance of speeds. Door to door travel times are infeasible to obtain using roadside readers but are easily obtained if GPS is used.

Roadside readers have the disadvantage that it is difficult to determine whether a vehicle made a stop between checkpoints or was merely delayed by traffic. There are algorithms to address this problem; they simply make system design somewhat more complicated.

Passive probe techniques show great promise for real time traffic operations monitoring, traveler information, deficiency monitoring, and project programming. They require a higher initial investment (if roadside readers are used) but have very minor incremental costs for gathering the data once the readers are in place. GPS eliminates the need for roadside readers, but requires more expensive in-vehicle units than ETC tags. GPS also requires some method for transmitting the data from the vehicle to the center. A method also must be found for distributing, installing, and later recovering the GPS units.

GPS units, unlike ETC tags, can be used to track door to door travel times for customer satisfaction monitoring. ETC tags can be traced only between roadside readers. Both methods can provide data for deficiency monitoring.

5.8 Transit Vehicle Tracking

Transit vehicle tracking is a technique to obtain travel times for transit. Various approaches possible for tracking transit travel times include the use of published schedules, the use of raw data collected by operators for on-time performance monitoring, placement of ETC tags on transit vehicles, and placement of GPS units in transit vehicles.

5.8.1 Coverage

Transit vehicle tracking is targeted exclusively to the transit mode. Transit vehicle travel times, which include delays to pick up and drop off passengers, are not representative of other modes. Though transit tracking techniques can provide relatively good geographic and temporal coverage, they cannot distinguish the trip purposes of travelers and thus cannot determine separate speeds various travel markets.

5.8.2 Cost

Published schedules are available at no cost. Development of the Regional Transit Database will facilitate obtaining transit schedules in electronic format, which will make it easier to extract point to point travel times for selected routes.

Obtaining raw travel time collected by transit operators for on-time performance monitoring would require a significant amount of labor to transmit, reformat, and process the data electronically since it would come in many different formats. It is not considered cost-effective to do so at this time.

The cost of placing ETC tags on buses is negligible if the system is used for general vehicle tracking and cost prohibitive if it is not.

Many of the region's operators plan to install GPS based AVL systems for fleet monitoring. As this becomes more widespread, the quality of the on-time performance data may improve; however, it is not expected to reduce the costs and difficulties associated with processing data in range of formats unless a concerted integration effort is undertaken.

5.8.3 Local Experience/Acceptability & Coordination Potential

There is plenty of experience among local transit operators with evaluating on-time performance. To date, there is no local experience with ETC tags on buses. Only three of the region's operators currently use GPS-based AVL systems and, with the exception of BART, they are not used specifically to monitor travel time or on-time performance.

5.8.4 Implementation Time

Transit vehicle tracking using published schedules can be implemented immediately. Tracking of individual vehicles will require several years for the transit operators in the region to obtain funding, and to acquire and install the necessary equipment. Portable GPS units might be used in the interim and rotated from vehicle to vehicle to obtain sample of vehicle performance, until the fleet is fully equipped.

5.8.5 Sufficiency

Tracking transit vehicles cannot provide door to door travel times. Rough information on travel time variance can be estimated from on-time performance data already collected by operators. For most operators, travel times obtained from published schedules is likely to be reliable within about 5 minutes system-wide. However, on-time performance can vary greatly among routes. If routes selected for monitoring included some with documented, poor on-time performance, it would be advisable to adjust the scheduled travel time accordingly. Use of schedules will not generate any data on variability. The on-time performance statistics reported by operators are a measures of variability. These measures vary from operator to operator based on individual definitions of "on-time", and could not be adapted to the 90 and 10 percentile travel time format described in Section 5.1.

The use of published transit schedules (with on-time performance data as necessary) is the most cost-effective of the methods considered for obtaining transit travel times for customer satisfaction monitoring. Another method would be required for certain operators, such as Muni, that do not effectively monitor on-time performance.

Use of transit schedules would be unsatisfactory for all the other system monitoring uses which require more detailed information about the discrepancy between the scheduled and actual travel time.

5.9 Truck Tracking

Truck tracking is a technique to obtain travel time data specifically for the freight mode. Two approaches were considered. One is to recruit operators to report travel times from their existing sources. The other is to loan GPS and travel time recording equipment to the operators that do not currently have such equipment and sharing with the operator the collected data. The latter approach has been used by the Air Resources Board to study truck emissions and was well received by participating operators.

5.9.1 Coverage

Truck tracking is targeted exclusively to the truck freight mode. Travel times include delays to pick up and drop off loads and are not representative of other modes. This technique can provide relatively good geographic and temporal coverage, but sample sizes are generally limited.

5.9.2 Cost

The costs of contacting and securing travel time data from existing sources maintained by truck operators would be negligible from the point of view of the public agency, but should include the need to spend some time in face to face meetings securing truck operator cooperation. This method is costly to the freight operators. In the travel time pilot project field tests, freight operators had to spend considerable time transcribing driver logs or other information sources to provide meaningful data. Responsibility falls to the public agency to minimize the burden born by the operators and convince the operators that it is worth their time to participate.

GPS tracking is one means of minimizing the work required by freight operators. It would require about $100,000 in capital costs to obtain 14 GPS units for loan to the freight carriers. It is estimated that a minimum of 14 GPS units would be required to obtain freight travel times for the entire MTS system in the course of a year. Another $100,000 in annual survey costs would be required to recruit carriers, install and remove the GPS units, and reduce the data.

5.9.3 Local Experience/Acceptability & Coordination Potential

There is no experience among agencies within the region working with truck operators to monitor truck travel times in this fashion.

5.9.4 Implementation Time

For either method, truck tracking will take some time to set up with cooperating operators, but probably could be implemented within a couple of years.

5.9.5 Sufficiency

Tracking trucks can provide dock to dock travel times. Good variance data will be difficult to obtain due to limited sample size, though some data could be collected by monitoring regular routes. Manually recorded travel time data tends to be rounded to the nearest 5 minutes and, since the driver logs the data is often taken from are used for enforcement of USDOT driver time rules, they may not always reflect reality. The use of GPS loan units offer more accurate data and appears to provide a good incentive to freight carriers to cooperate with a freight survey as the operators can gain valuable information on the operation of their trucks.

Freight carrier travel time monitoring would be most appropriate for customer satisfaction monitoring. Limited sample size suggests freight tracking methods may be less useful for identifying freight-related deficiencies than other segment monitoring methods applied to heavy freight facilities.

Real time reporting for truck tracking is not feasible and probably not desirable. First, as with deficiency identification, data collected other monitoring methods on heavy freight facilities may have broader applications; second, truck operators may wish to screen data before releasing it to a public agency.

5.10 Trip maker Tracking - Traveler Surveys

Trip maker tracking using household and/or employer surveys is both a new and an old technique for measuring travel times. Prospective surveys recruit travelers in advance to keep a record of their travel. Retrospective surveys ask travelers about trips regularly or recently taken. Travelers have in the past been asked to keep diaries of the trips and travel times for the purposes of calibrating models of travel behavior, but not for the purpose of monitoring system performance.

5.10.1 Coverage

Household and employer surveys provide door to door travel times for all modes. Lesser used modes will tend to have small sample sizes in the surveys.

Traveler surveys provide good temporal coverage and allow direct inquiry into the trip purposes of travelers and thus can determine separate speeds and travel times for commute, non-commute, travelers with disabilities, and transit dependent markets. The only difficulty is securing an adequate sample size for each market.

Traveler surveys can provide relatively good geographic coverage, but specialized sampling strategies may be required to secure adequate samples for a particular corridor or facility. For example, license plates of vehicles using the corridor may need to be recorded and post cards sent to the registered owners.

5.10.2 Cost

Prospective home interview surveys are potentially the most accurate approach but their cost can reach $150 per completion. Retrospective household surveys can be completed for half this cost, but collect less accurate travel time data. In general, costs decrease as the acceptable sample bias increases. In particular, employee surveys which reach only workers can cost as little as $5 per completed survey. A website survey would reduce this cost a little more, but has significant demographic bias risks.

5.10.3 Local Experience/Acceptability & Coordination Potential

MTC and other agencies including RIDES have ample experience with household and employer surveys.

5.10.4 Implementation Time

The surveys could be implemented immediately upon securing the necessary funding.

5.10.5 Sufficiency

Traveler surveys directly provide door to door travel time information. Variance information may be difficult unless large sample sizes are obtained or the traveler is trusted to correctly recall past variations. There appears to be good evidence indicating the lack of precision of travelers' recollections of travel time. Even logging of trips as they occur is not totally reliable. The use of trip logs in combination with GPS receiving and recording units has revealed many discrepancies between the logs and the GPS units. The biggest problem is missed/forgotten trips. Reported data, even with missed trips, should be accurate enough for detecting trends.

Trip maker tracing using either retrospective or prospective household surveys are ideal for customer satisfaction monitoring. Retrospective surveys of employees, using one of the ongoing survey efforts, such as RIDES, are the least expensive method and would provide sufficient accuracy for measuring satisfaction.

The survey methods though are too expensive and not accurate enough for deficiency identification, and project programming. GPS units would overcome some of the concerns related to accuracy but would require an enormous sample to be useful and would therefore be more expensive than specific segment monitoring using other means. The survey methods are not timely enough for traffic operations monitoring, and traveler information.

5.11 Evaluation Summary

Exhibit 16 summarizes the evaluation of the data collection techniques discussed above.

Exhibit 16: Evaluation Summary

Method	Sufficiency			Coverage			Cost		Local Experience	Observations
	Best Applications	Accuracy	Variability	Geographic	Time of Day/ Market[15]	Modes	Hardware[16]	Maint/Op (per year)		
Immediate Implementation Possible										
Floating Cars • GPS • DMI	• Deficiency ID • Project Program.	Excellent	Limited	Full coverage very costly	Time of day: poor (best for peak)	No Bike	$50,000	$300,000	Excellent	• Cost inefficient but low risk • Too costly to collect data over broad arterial network or in non-peak periods • Feasible but very costly to collect data for transit, freight, and HOV modes
Transit Schedules	• Customer Perception	Fair	None	Full coverage in-expensive	Time of day: all	Transit only	None	Negligible	Excellent	• Not uniformly reliable for individual routes; may supplement with on-time performance statistics • Not reliable for systems that do not routinely monitor on-time performance
Retrospective Survey • Home telephone • Employer • Piggy back on other efforts	• Customer Perception	Limited	Limited	Full coverage possible; costs vary	Markets: primarily commute	No Freight	None	Home: $50,000 per 1000 complete Employer: $5,000 per 1000 complete Piggyback: negligible	Excellent	• Data generally less precise than prospective surveys • Costs decrease as tolerance for bias increases (sampling can be less rigorous, e.g. some employee surveys); makes data less useful for other planning purposes; biases in a web-based survey are most likely unacceptable • Other variations on sampling possible • RIDES effort is most comprehensive existing commuter survey; more complicated to coordinate with many smaller surveys.
Prospective Home Survey (Manual trip diary)	• Customer Perception	Fair to Good	Fair	Full coverage costly	Markets: all	No Freight	None	$150,000 per 1000 complete	None	• Most expensive and most accurate survey method • GPS diaries have excellent accuracy but increase costs and require a long term implementation time frame
Short Term Implementation Possible (1-2 years)										
Freight Tracking • Logs • GPS	• Customer Perception	Excellent	Yes, but limited by sample size	Coverage dependent on participants	Time of day: all	Only Freight	$100,000	$100,000	Limited	• Reliance on carriers to provide data likely impractical due to imposition on carrier • Loaner GPS units costly but provide incentive for carrier participation and increase accuracy

[15] Time of day refers to peak, off-peak, night, and weekends. Market refers to commute and non-work.

[16] To establish a common basis for comparison, costs were estimated for full MTS coverage unless otherwise specified.

Exhibit 16: Evaluation Summary (cont.)

Method	Sufficiency			Coverage			Cost		Local Experience	Observations
	Best Applications	Accuracy	Variability	Geographic	Time of Day/ Market	Modes	Hardware	Maint/Op (per year)		
Short Term Implementation Possible (1-2 years) cont.										
Roadside Sensors • Loops/ RTMS (spot speeds)	• Deficiency ID • Project Program. • Real Time Ops./ Traveler Information	Excellent (for spot speeds, assuming adequate maint.)	Excellent	Full coverage costly	Time of day: all	Best for freeways	$4,000,000 to complete existing freeway system	$50,000	Good	• Loops with communications currently operational for 1/6 of fwy system; next 1/6 scheduled to be operational by 2001. • Current loop infrastructure unreliable; fewer than 1/3 of loops actually functioning at any time • Possible to extrapolate travel time from speed data, depending on accuracy need • Vehicle signature matching, under development; may generate travel time data in the long term.
Long Term Implementation Possible (3-5 years)										
ETC Passive Probes	• Deficiency ID • Project Program. • Real Time Ops./ Traveler Information	Excellent	Excellent	Full coverage costly	Time of day: all	All, bike possible	$9,000,000	$300,000	None Yet	• ETC tags cheap, but roadside readers costly; therefore costly to get broad coverage, especially on arterials and therefore on transit • Deployed successfully in other areas • Vehicle type identification non-trivial to implement
Areawide Passive Probes (GPS)	• Customer Perception • Deficiency ID • Project Program. • Real Time Ops./ Traveler Information	Excellent	Good	Full coverage inexpensive	Time of day: all	No bike	$9,000,000	$300,000	None Yet	• GPS units currently expensive and complicated to install (by operators); costs may decrease but this is a risk factor • Collecting data from GPS units is costly, and likely inconvenient • The only non-survey method that can collect door-to-door travel time.
Digital Aerial Photos	• Deficiency ID • Project Program.	Good	Fair	Full coverage costly	Time of day: low light limitation	No Bike	$50,000	$300,000	Limited	• Low light limitation may exclude portions of the peak periods in winter • Photo measurement is labor intensive and no feasible without advances in digital processing
License Plate Matching w/ OCR	• Deficiency ID • Project Program. • Real Time Ops./ Traveler Information	Excellent	Excellent	Full coverage costly	Time of day: all	No bike	$15,000,000 (assuming permanent stations)	$300,000	None	• Manual matching possible in short term but cost prohibitive without (long term) advances in OCR • Video equipment also expensive, especially to cover broad arterial network; therefore limited transit coverage

6. Study Conclusions

MTC initiated this study to help inform partnership discussions on whether and how to monitor travel time and variability of travel time on the Metropolitan Transportation System. MTC believes that tracking these customer-oriented performance measures can facilitate a better understanding of how customers experience the system, allow us to trace changes in performance over time, and identify areas that may require further investigation. The data could be periodically collected and published in a "state of the system" report shared with partner agencies, decision makers, and the public.

A state of the system report serving this purpose incorporates two of the potential data applications explored in the previous chapter: 1) understanding customer perceptions of travel time and variability and 2) identifying system deficiencies for further study. The first application may be addressed by reporting travel time by mode and/or market for selected origin-destination pairs. The second may be addressed by reporting data for selected MTS facility segments and summary statistics by corridor or county.

The report should cover a broad range of modes and markets while keeping costs reasonable. It is desirable to collect data that may be used for other system monitoring or planning applications; thus we are interested in a fairly high level of accuracy, as long as it can be achieved at a reasonable cost.

Based on the results of the evaluation, this study offers the following conclusions on data collection methods to support of a state of the system report:

- Survey methods are best suited to collect data on customer perception and can be implemented immediately. Survey methods can cover travel for all modes except freight (see discussion below) though general surveys will collect little data on the lesser used modes proportionate to their share. MTC currently conducts comprehensive prospective household travel surveys approximately every 5 years. While it would be prohibitively expensive to increase the frequency of these efforts, these efforts can serve as anchors or calibration points for less comprehensive surveys conducted more frequently.

  Retrospective surveys will provide travel time and variability data sufficiently accurate for this purpose, as we are interested in perception. The biggest question, to be answered through discussions with MTC's partner agencies, is the appropriate level of sampling rigor, which will affect a number of factors including: the ability to collect data on non-commute markets and less frequently used modes such as transit, bikes, and HOV; cost; and the potential to use the data for other purposes. Any of several variations would be appropriate:

  – Piggy back on the RIDES commute survey – This survey, conducted annually, generates statistically significant data, including travel time, for commuters by county of residence. The travel time project developed a survey questionnaire containing questions that could be added to the RIDES survey. It does not make sense to duplicate the RIDES survey with an independent household telephone survey.

  – Survey employees through their employers – This method is likely to result in a more biased sample due to uneven employer recruitment and participation. However, it is better suited than a telephone survey to tracing travel in corridors, as specific destination sites could be targeted. The bias would be more pronounced, but possibly acceptable, if recruitment costs were reduced by using existing networks of volunteers to distribute surveys in the public and private sectors. (This approach was tested in the Travel Time Pilot Project.)

- Use license plate mail-back and transit intercept surveys (not explored in this study) to sample travelers in specific corridors. This could be costly and requires further investigation, but could provide good general corridor planning data.

Survey methods provide an opportunity to ask a range questions related to customer satisfaction with the transportation system. For example: what aspects of the trip most need improvement? How reliable is the transportation system? The opportunity is somewhat more limited if travel time questions were piggy-backed on other survey efforts because response rates tend to decrease as survey length increases.

- Segment performance data collected for deficiency monitoring could compliment the survey data in two ways: a) whereas it is costly to target data collection to specific facilities or corridors with surveys, this is easily done with segment monitoring; and b) segment data can provide a reality check for perception data collected through survey efforts, making it more reliable for identifying problems or for other studies. The reality check functions both for data collected within a given year (Are the reported travel times reasonable?) and in examining trends over time (Has the trip gotten worse even though commuters don't perceive it?)

Though this study identifies candidate methods, this study does not recommend a method for immediate implementation. The evaluation in Chapter 5 identifies five methods well-suited for segment monitoring on roadway facilities: floating cars, roadside sensors (spot speeds or extrapolation), passive probes (ETC or areawide), digital aerial photography, and license plate matching with OCR. The methods have a number of trade-offs related to type of data, stage of development, current infrastructure. With the exception of floating cars and aerial photography all of these methods are potentially well suited for real-time applications and require significant infrastructure investment. Even the existing loop surveillance system, in which the region has already invested significantly, would require additional investment to expand and maintain, and to retain historic data.

Because state of the system report alone likely would not justify such a sizable investment but the combination of real-time and historic data applications may, we recommend, MTC defer a decision until the completion of the recently initiated project to develop a data coverage plan for TravInfo. This study, to be completed in summer 1999, will research the types of real-time information travelers seek and analyze existing and potential data sources. If, as is likely, the TravInfo study recommends data collection methods that can provide travel time or other data useful for deficiency monitoring, this data should certainly be used for the state of the system report. The challenge at that point will be to decide how to sample and supplement the TravInfo data for the state of the system report. The TravInfo project should actively consider the need to sample real-time data collection systems for historic data such as the state of the system report.

- Both the surveys and the roadway segment monitoring methods can provide data on variability. The surveys provide perceived variability for all modes, while most of the candidate segment monitoring methods can provide variability data in the 90/10 percentile format suggested in the hypothetical specifications for the state of the system report. For the time being, transit on-time performance data, variable among operators, is the best source of data on travel time variability for transit.

Additional conclusions relate to data collection for specific modes:

- Many of the roadway segment monitoring methods are best suited for freeways. This suggests MTC and the Partnership should be prepared to identify a subset of MTS arterials for monitoring. If the TravInfo project does not incorporate these arterials, MTC may wish to consider alternatives such as floating car runs or digital aerial photography, as the technology develops. Another alternative is to summarize county CMP findings on roadway LOS, though this strays from the original customer-oriented model.
- Monitoring of HOV lanes should be possible with any of the five candidate methods for roadway segment monitoring, though this may require additional infrastructure. Survey data can complement this data by providing data for HOV travel that does not occur exclusively in HOV lanes.
- Though the use of travel time data estimated from transit schedules is not a good method for deficiency identification, it would compliment data collected through survey efforts. For example, the report could include segment travel times for selected transit routes in the travel corridor for which roadway data is collected. The evaluation shows schedules, supplemented as necessary by route-level on-time performance data, are a good means of getting segment travel time data. As AVL systems come on line in the long run (3-5 years), they may provide better segment travel time and variability data for transit; however, integrating data from a number of sources and in a number of formats could still be a barrier to using this data for a state of the system report. Data integration may be addressed by TravInfo for real-time applications, in which case the biggest challenge for the state of the system report would be to devise a sampling plan and recording system.
- The best means to collect data applicable to the freight market is to ensure general data collection efforts on freeways and arterials cover heavy freight facilities during periods of peak freight movement. Despite a high level of willingness to cooperate among members of MTC's Freight Advisory Council, it is prohibitively complicated and costly to survey the freight market for a regional state of the system report at this time. Using data, such as driver logs, already collected by freight operators requires excessive work on the part of the operators. Loaning GPS units to operators is likely not worth the cost unless they are a) used broadly for other trip makers or b) used for a more comprehensive study of freight movement.
- It is reasonable to rely on survey methods to provide data on bicycle travel. General survey methods will generate relatively little data on bicycle travel, as is proportional to the small bicycle share and inversely proportional to the wide variety of routes taken for trips. If employer-based surveys are used, effort might be made to include bicycle friendly destinations. For any survey method, bicycle data could be supplemented by distributing surveys through bicycle-oriented e-mail and mailing lists maintained by RIDES. This data, however, would be anecdotal; it could not be mixed with general survey data to calculate corridor or county-wide statistics, nor could it be assumed to be representative of typical bicycle trips.